APPENDIX A: 2010 *E. COLI* MONITORING DATA AND DAILY PRECIPITATION, BY SITE

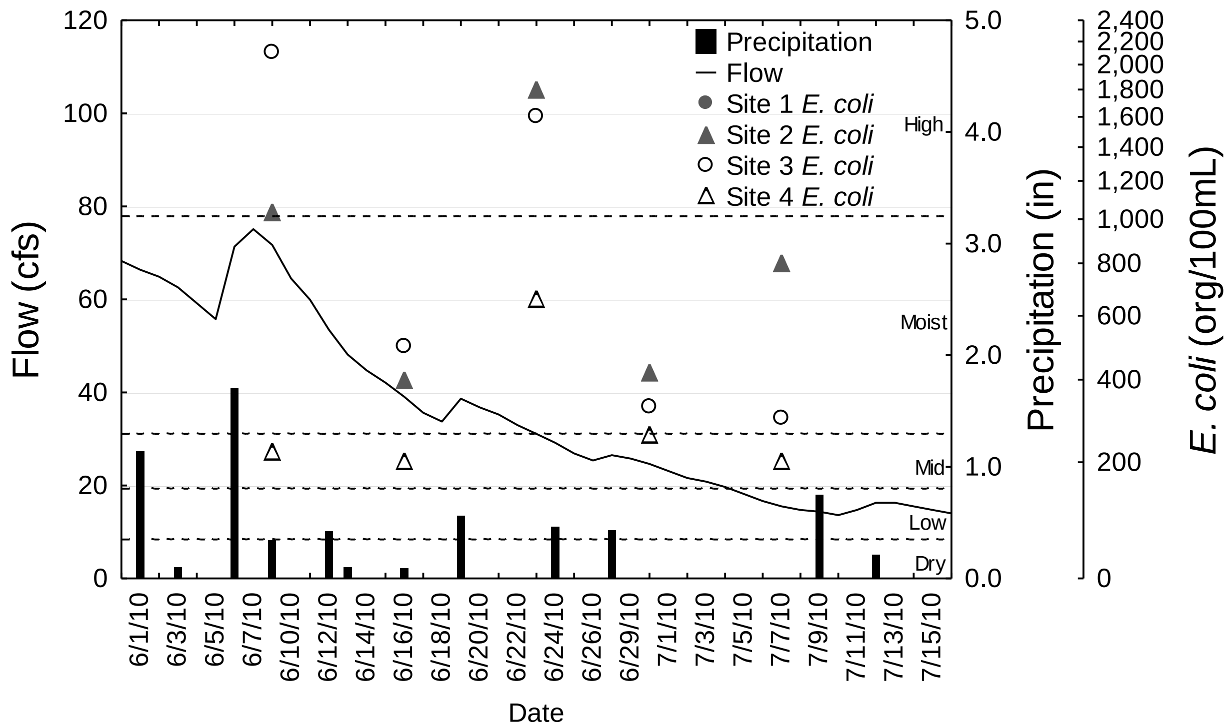

Figure 1. Daily precipitation, daily flow and *E. coli* concentrations in the Pigeon Lake – Pigeon Creek watershed (HUC 040500011001).

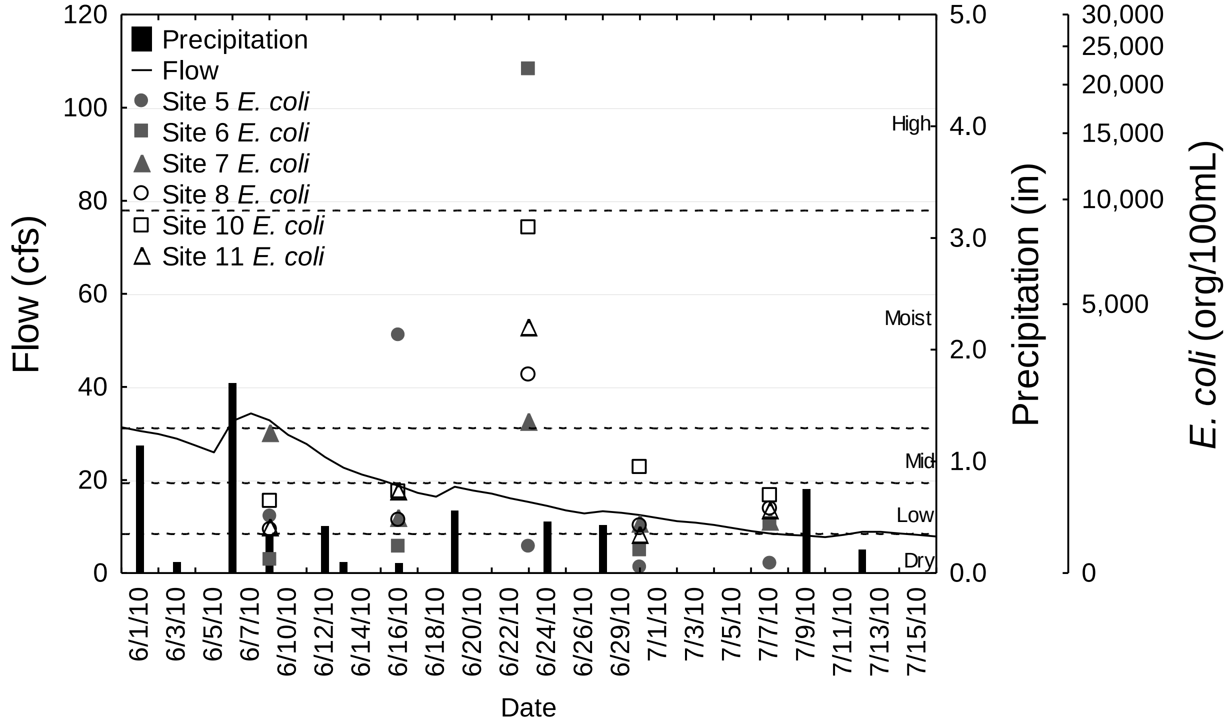

Figure 2. Daily precipitation, daily flow and *E. coli* concentrations in the Mud Creek – Pigeon Creek watershed (HUC 040500011002).

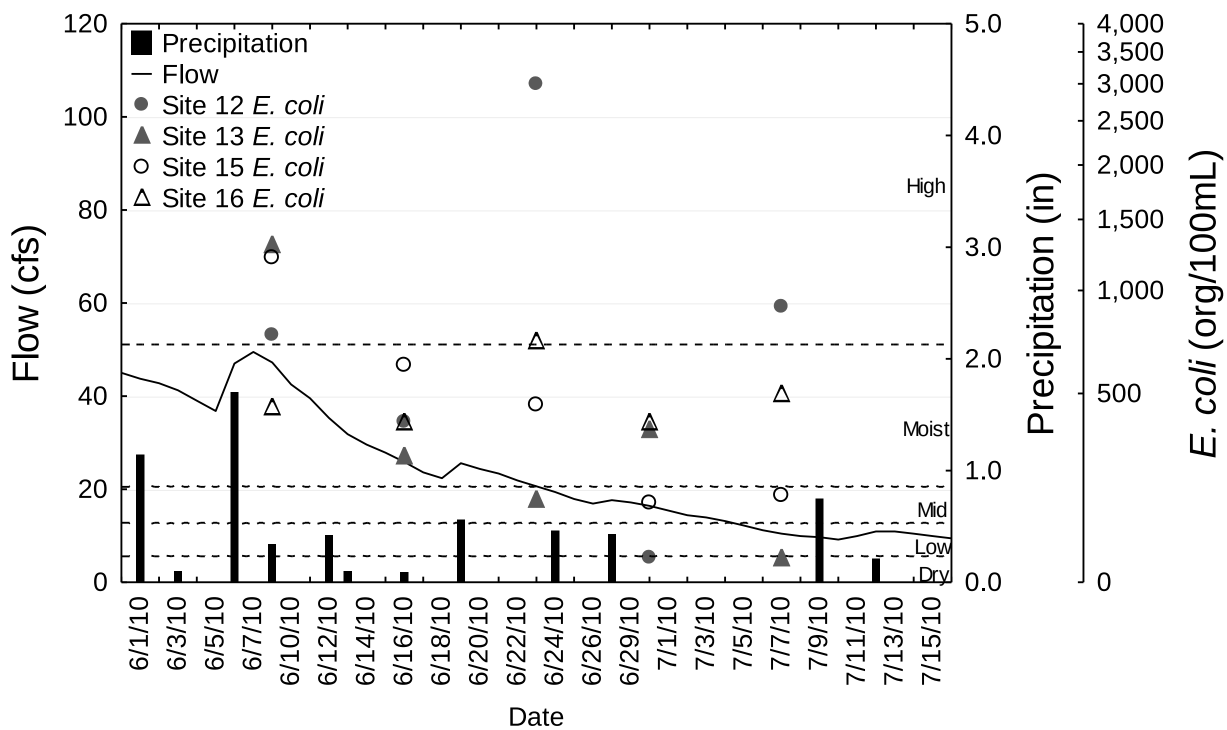

Figure 3. Daily precipitation, daily flow and *E. coli* concentrations in the Long Lake – Pigeon Creek watershed (HUC 040500011003).

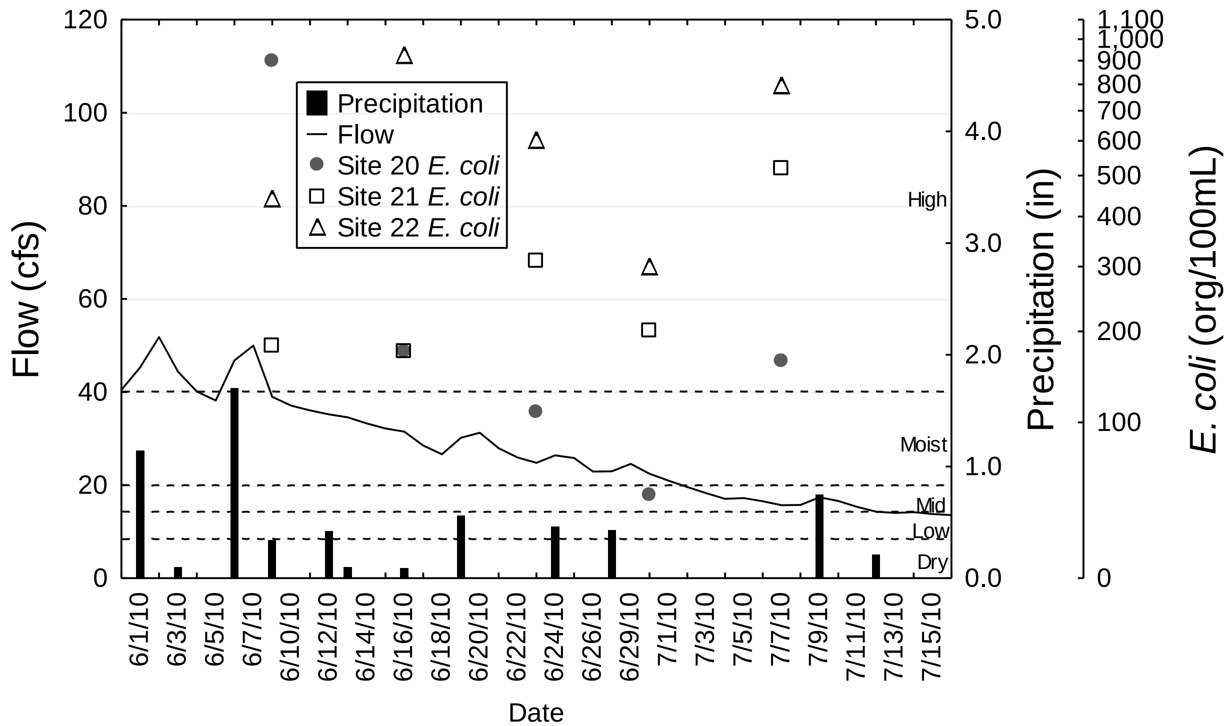

Figure 4. Daily precipitation, daily flow and *E. coli* concentrations in the Headwaters Turkey Creek watershed (HUC 040500011004).

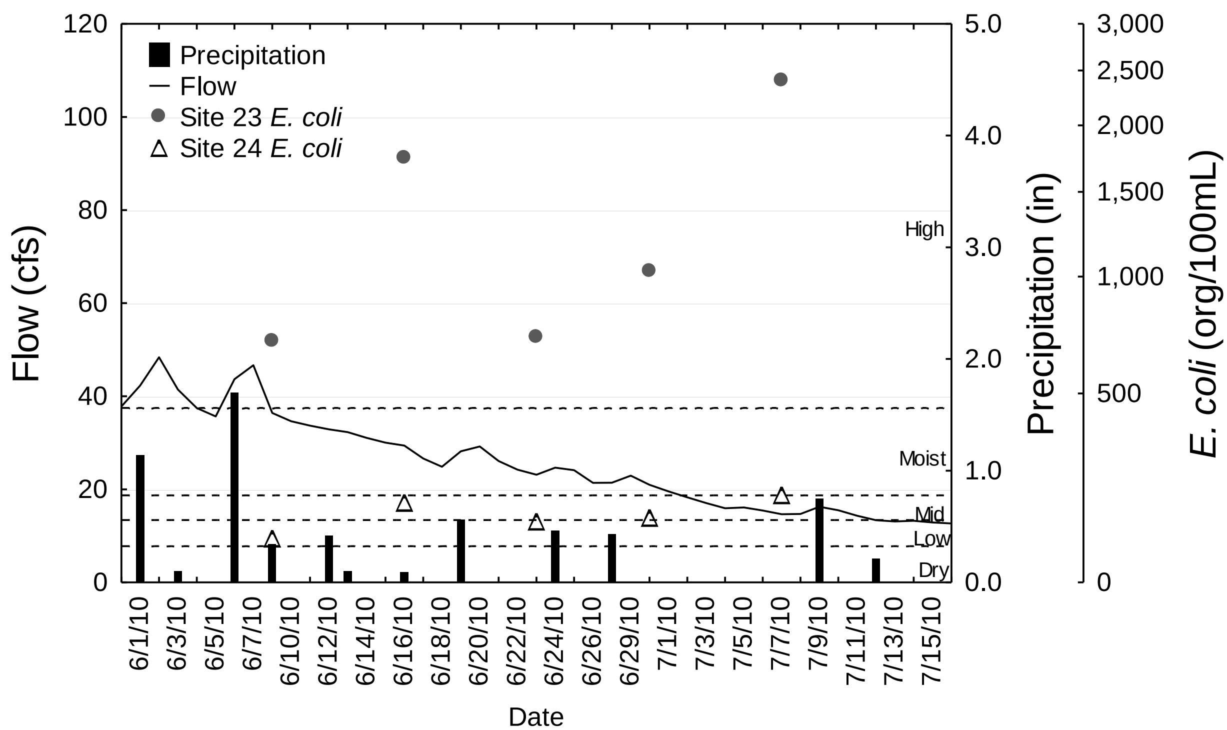

Figure 5. Daily precipitation, daily flow and *E. coli* concentrations in the Big Turkey Lake – Turkey Creek watershed (HUC 040500011005).

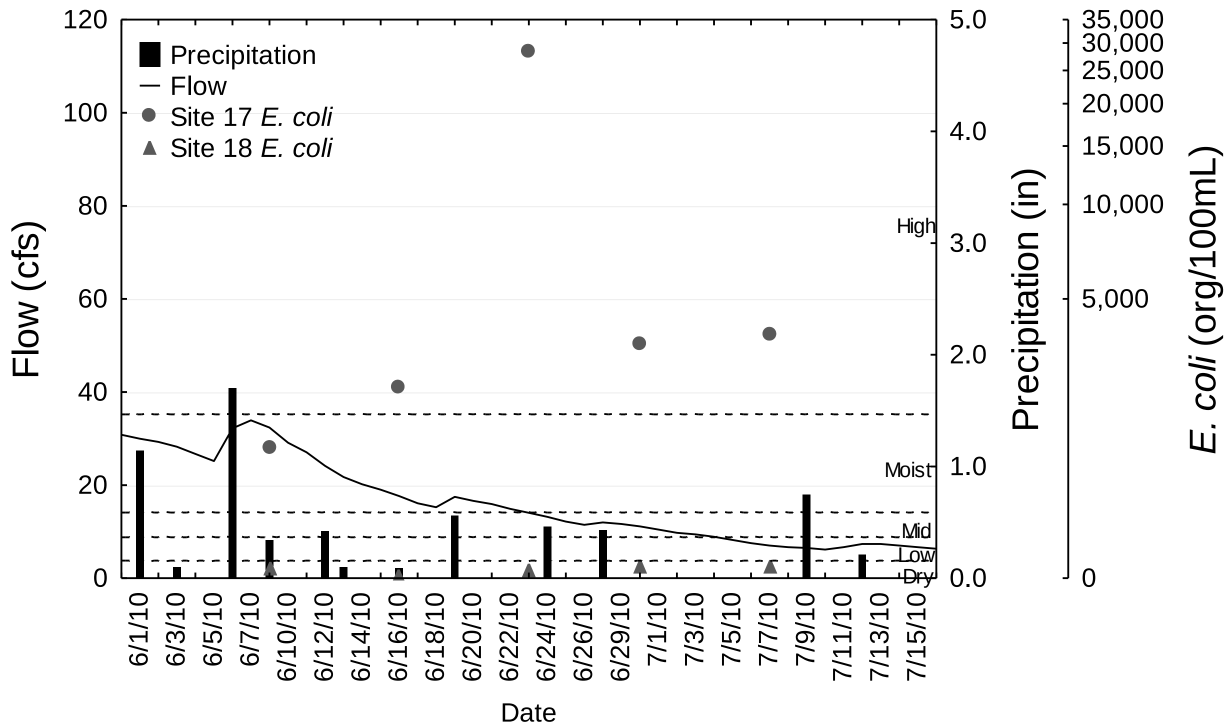

Figure 6. Daily precipitation, daily flow and *E. coli* concentrations in the Silver Lake – Pigeon Creek watershed (HUC 040500011006).

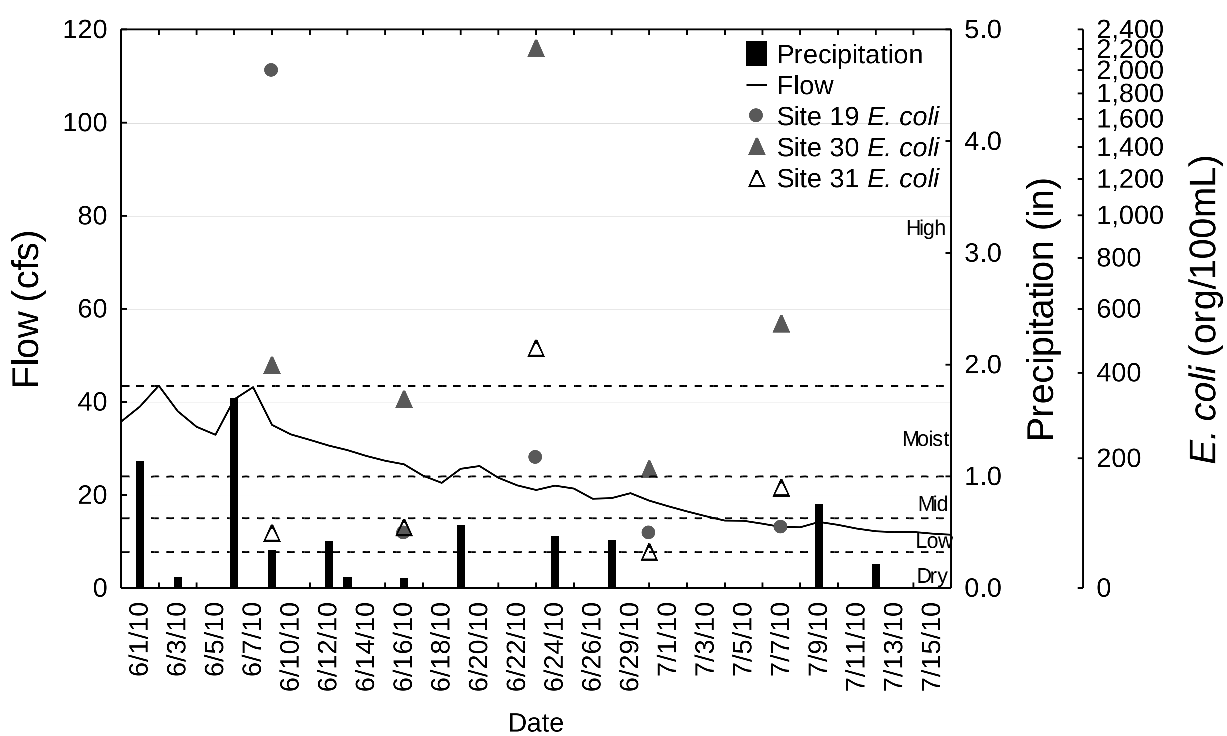

Figure 7. Daily precipitation, daily flow and *E. coli* concentrations in the Otter Lake – Pigeon Creek watershed (HUC 040500011007).

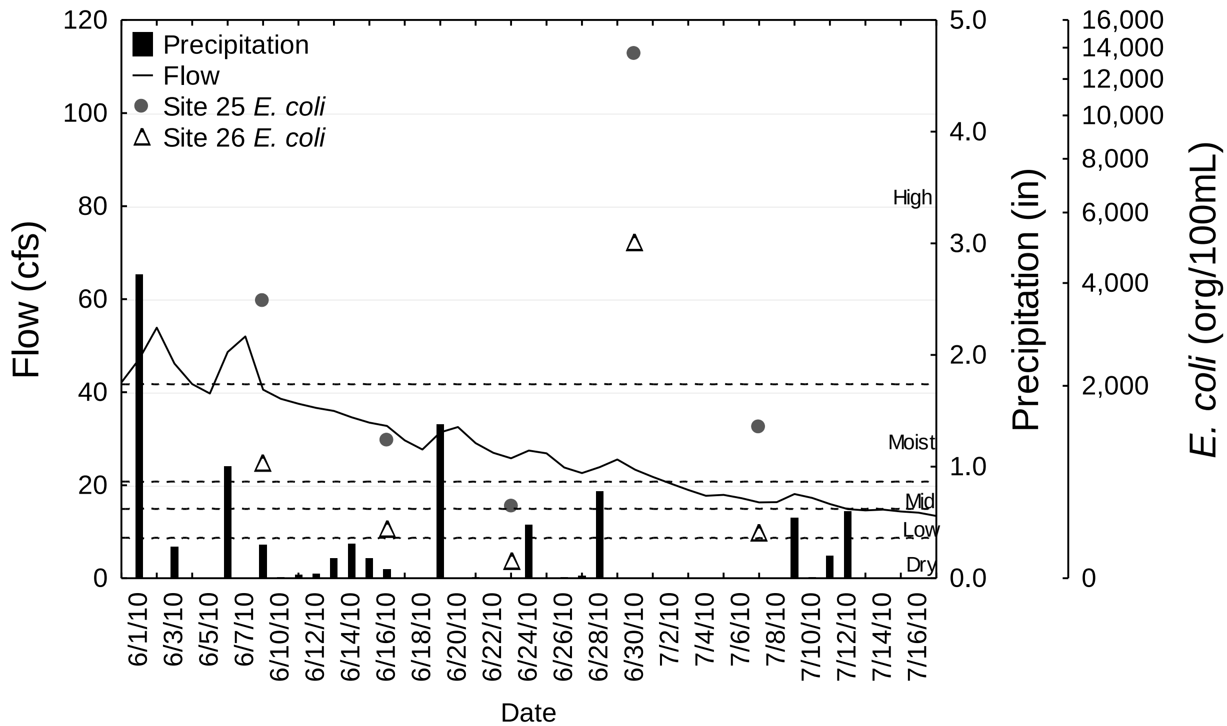

Figure 8. Daily precipitation, daily flow and *E. coli* concentrations in the Little Turkey Lake – Turkey Creek watershed (HUC 040500011008).

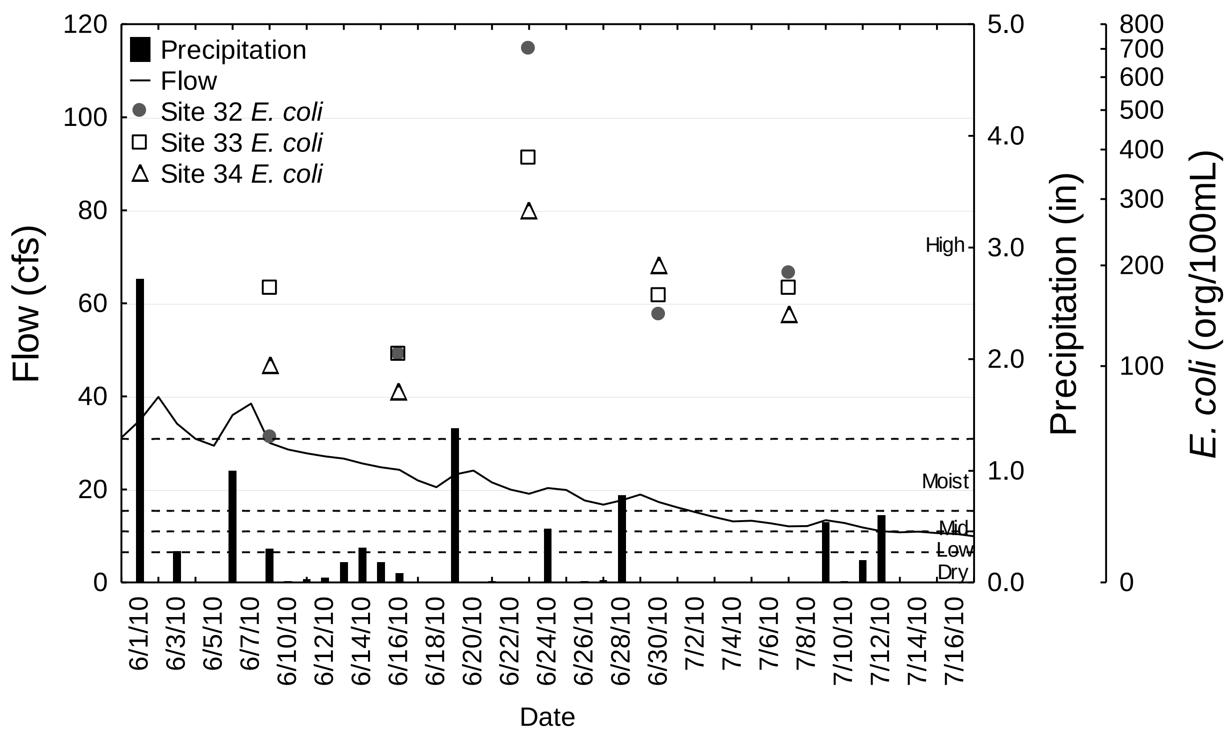

Figure 9. Daily precipitation, daily flow and *E. coli* concentrations in the Green Lake – Pigeon Creek watershed (HUC 040500011009).

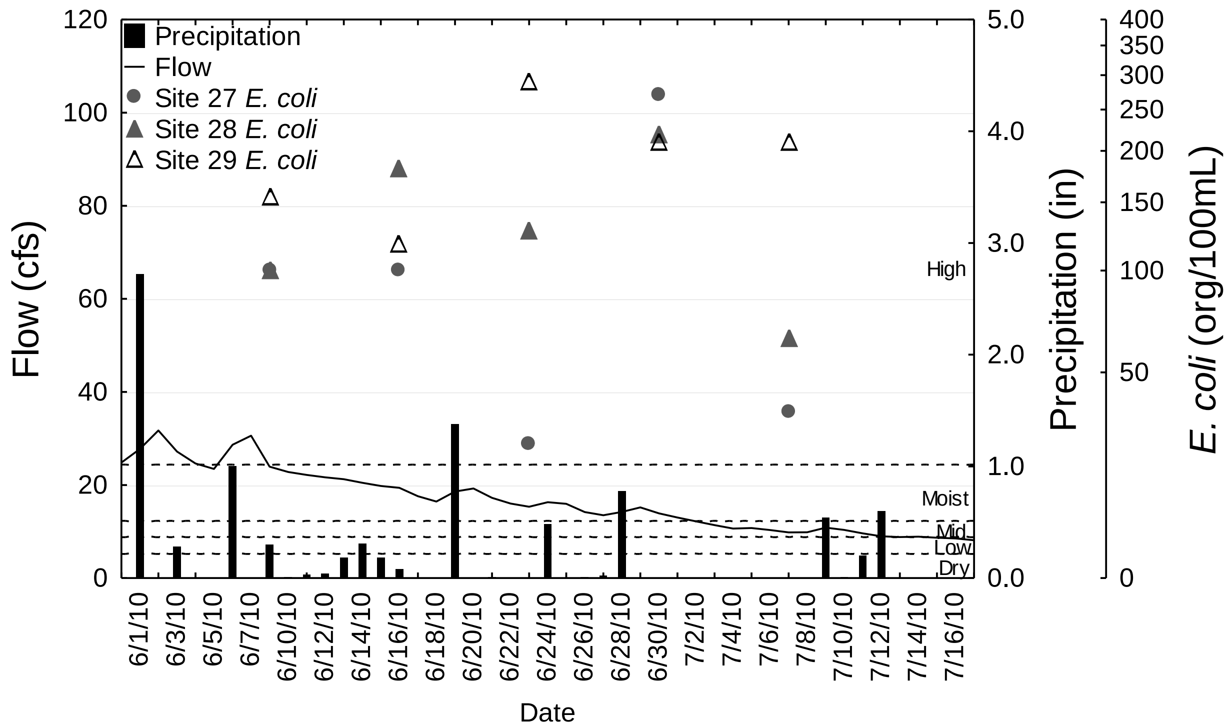

Figure 10. Daily precipitation, daily flow and *E. coli* concentrations in the Mongo Millpond – Pigeon Creek watershed (HUC 040500011010).

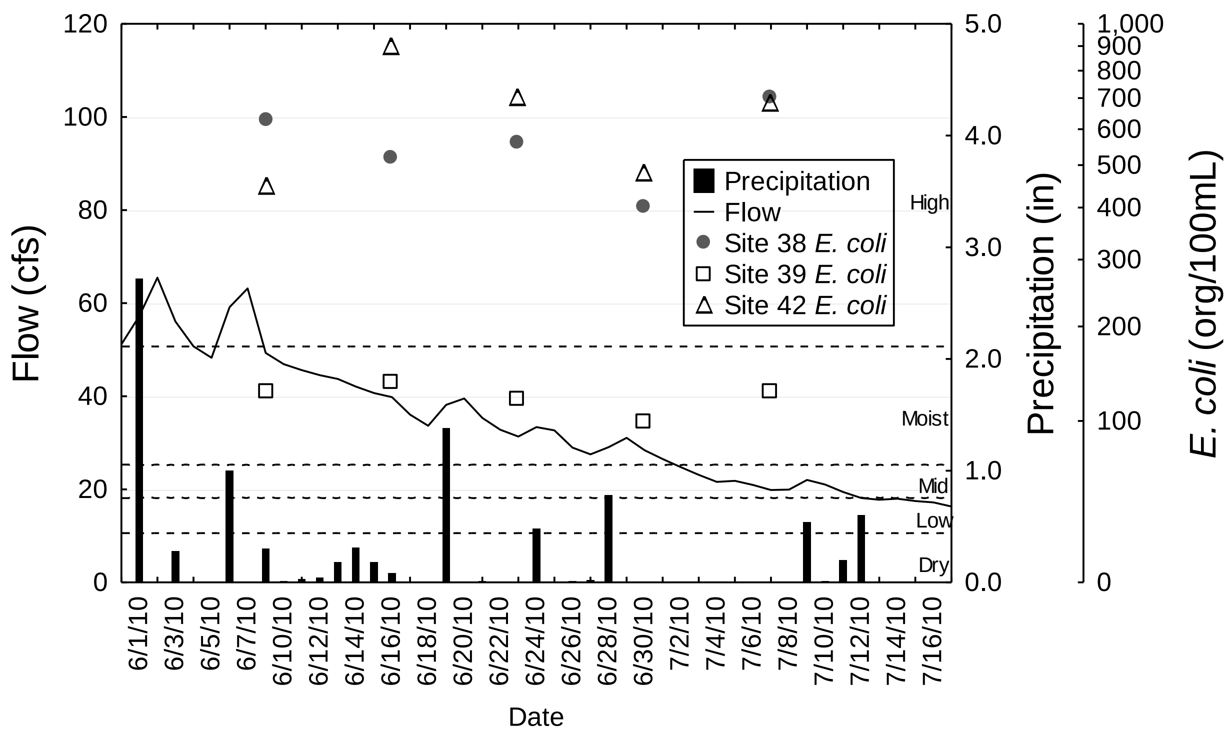

Figure 11. Daily precipitation, daily flow and *E. coli* concentrations in the East Fly Creek watershed (HUC 040500011101).

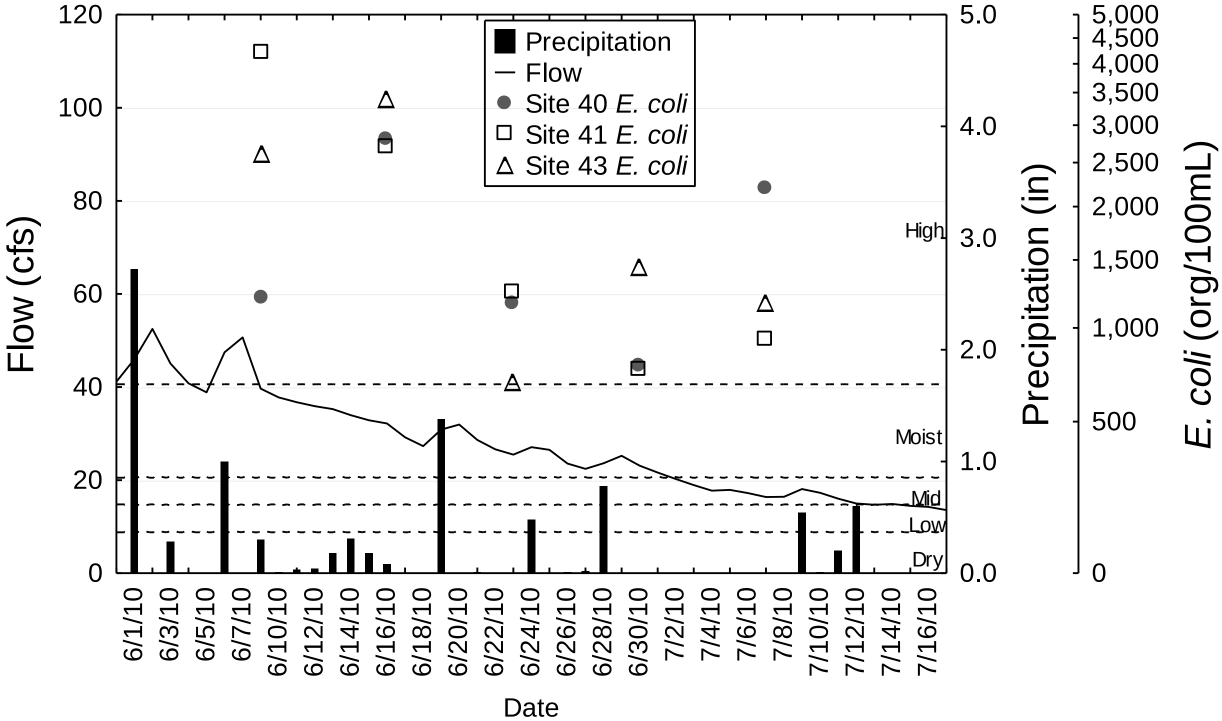

Figure 12. Daily precipitation, daily flow and *E. coli* concentrations in the Fly Creek watershed (HUC 040500011102).

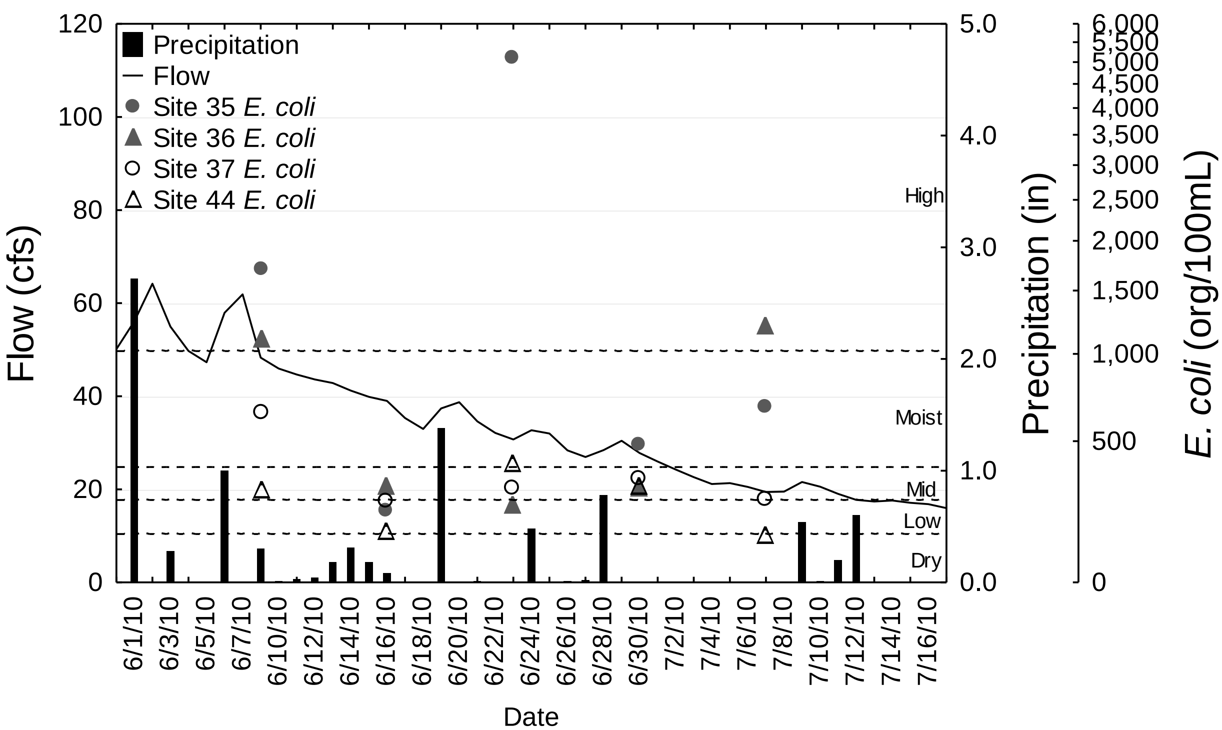

Figure 13. Daily precipitation, daily flow and *E. coli* concentrations in the Cline Lake – Pigeon River watershed (HUC 040500011103).

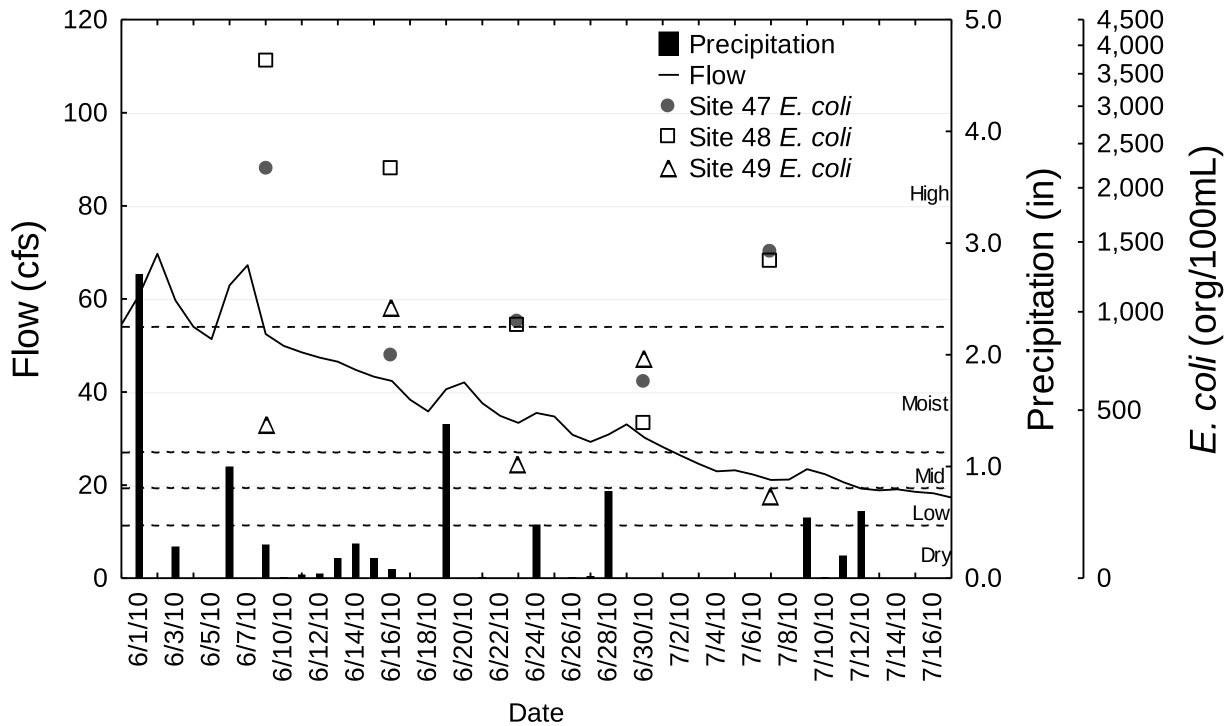

Figure 14. Daily precipitation, daily flow and *E. coli* concentrations in the Buck Lake – Buck Creek watershed (HUC 040500011104).

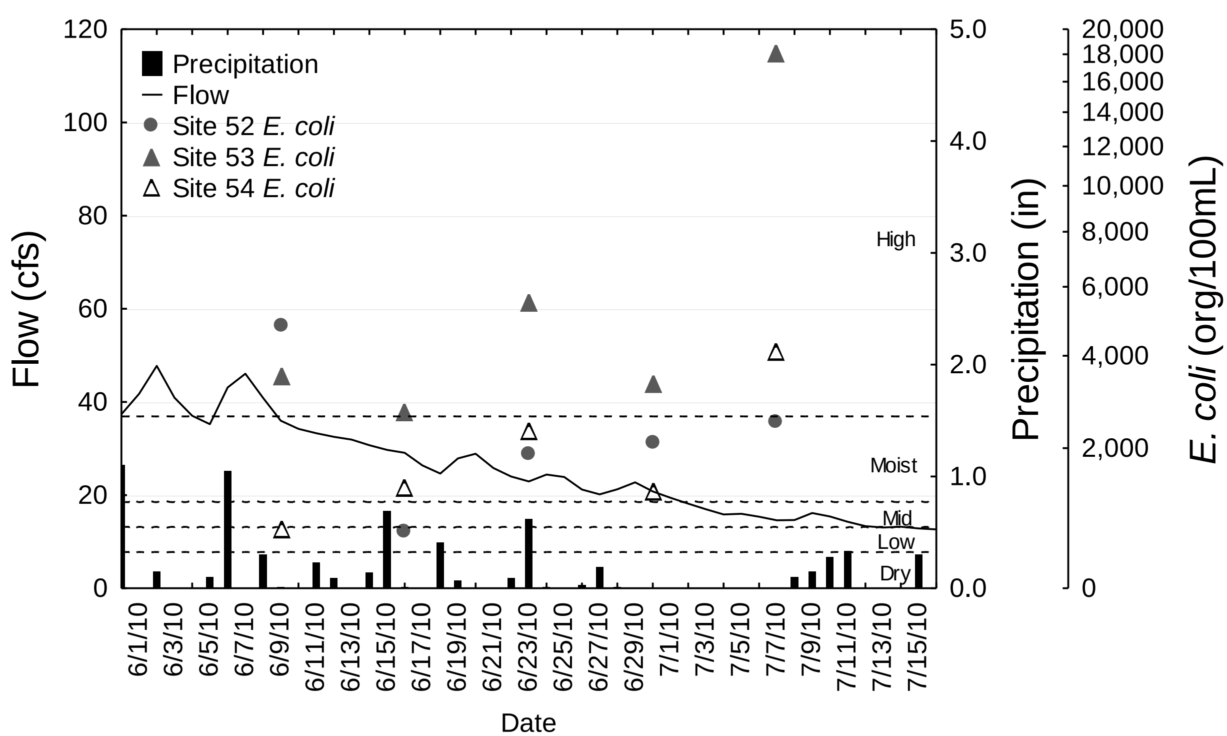

Figure 15. Daily precipitation, daily flow and *E. coli* concentrations in the Page Ditch watershed (HUC 040500011105).

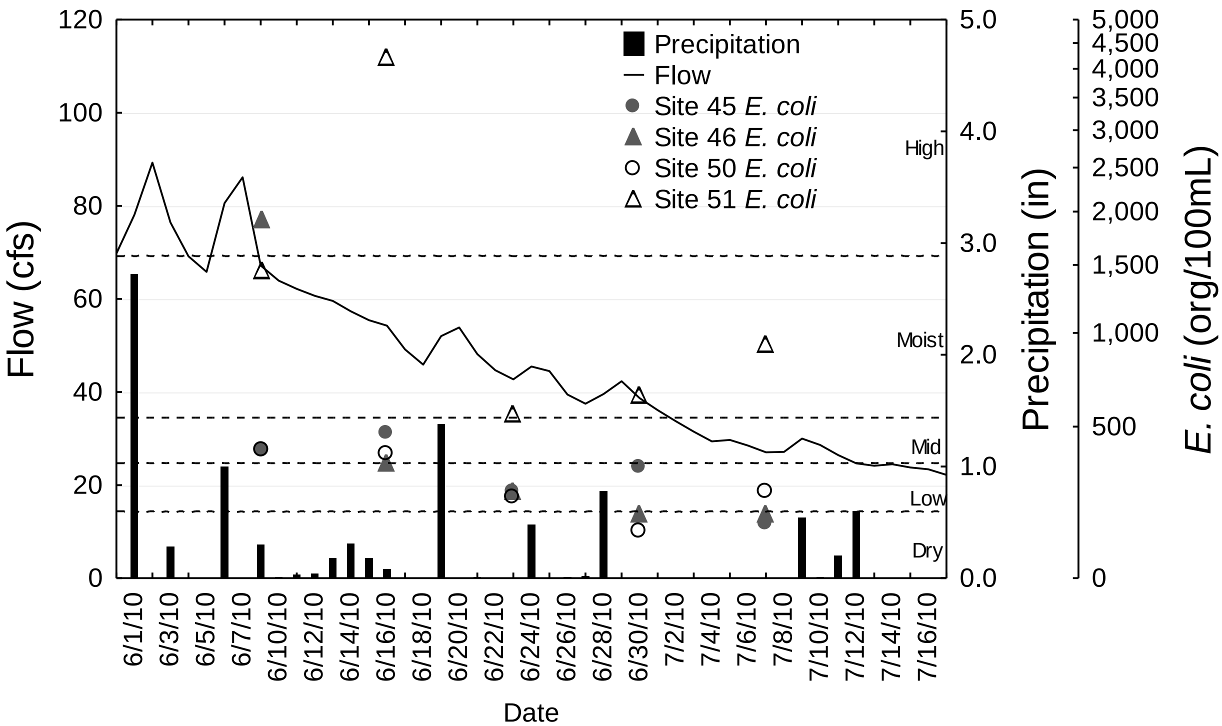

Figure 16. Daily precipitation, daily flow and *E. coli* concentrations in the VanNatta Ditch – Pigeon River watershed (HUC 040500011106).

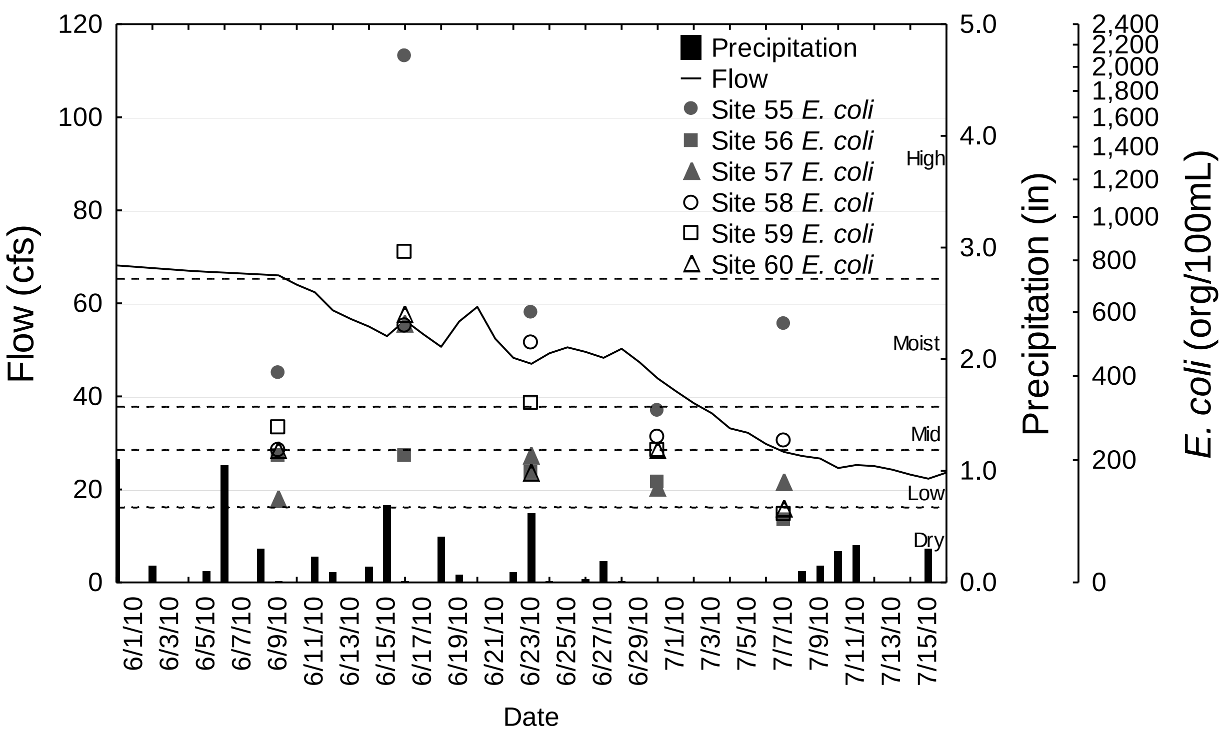

Figure 17. Daily precipitation, daily flow and *E. coli* concentrations in the Stag Lake – Pigeon River watershed (HUC 040500011107).

APPENDIX B: SECONDARY DATA

B.1 Stream data from Steuben SWCD

These secondary stream data were provided from Steuben SWCD. Applicable lake inlet and outlet data were reviewed for consistency with the lake TMDL studies.

Table 1. Steuben SWCD stream water quality data from Site 1 – Pigeon, East Ray Clark Road at culvert, below juncture with the Ryan Ditch

Sampling Date	5/26/2010	7/28/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	142	560	420
E-coli collection date (if different)			
Total Phos. (ppm)	0.16	0.02	0.03
Total Suspended Solids (ppm)	29	3	3
D.O.	5.11	9.32	8.72
pH	7.22	7.95	7.92
Temp. (c)	19.0	22.9	19.5
Specific Conductance	455	758	771
Post Rain Event	*		
CFM Discharge Estimate	2359.67	116.78	337.90
T.S.S. Loading Estimate Kg/day	2788.68	14.28	41.31
Phos. Loading estimate Kg/day	15.39	0.10	0.41

BDL= below detection limit

Table 2. Steuben SWCD stream water quality data from Site 2 – Pigeon Creek, Pigeon Lake Inlet

Parameter	10/31/2007	5/23/2008	7/24/2008	9/14/2008	5/22/2009	7/22/2009	8/19/2009	8/24/2009	5/26/2010	7/28/2010	8/24/2010
E-coli, (CFU or colonies/100 ml)	108	130	382	240	345	512	3400	240	296	254	720
E-coli collection date (if different)		5/22/2008									
total phosphorus (mg/l)	0.018	<.01	<.01	0.02	0.04	<.01		0.02	0.16	0.02	0.03
total suspended solids (mg/l)	2.8	21	9	47	22	<1		20	44	1	6
dissolved oxygen (mg/l)	10.22	8.71	15.04	6.95	8.02	9.08		8.23	6.50	9.17	7.63
pH	8.11	7.37	8.00	7.23	7.59	7.96		7.72	7.40	7.94	7.84
temperature (C)	19.9	12.2	21.8	19.5	18.6	18.8		23.0	19.8	23.5	18.3
specific conductance (µS·cm-1)	n/d	658	721	575	502	754		n/d	481	763	759
conductivity (µS·cm-1)								800			
rain event (yes or no)	no					yes			yes		
discharge estimate (CFM)	720.58	958.99	468.18	754.44	1398.00	776.45		1034.44	2359.67	116.78	337.90
T.S.S. loading estimate (kg/day)	82.22	820.69	171.71	1445.02	1253.37	BDL		843.11	2788.68	14.28	41.31
total phos. loading estimate (kg/day)	0.52	BDL	BDL	0.61	2.28	BDL		0.84	15.39	0.10	0.41
total nitrate loading estimate	17.91										
Biological Oxygen Demand (BOD) (5 day ppm)	3										
nitrate/nitrite	0.61										
nitrate	0.61										
nitrite	0.00										

BDL= below detection limit

Table 3. Steuben SWCD stream water quality data from Site 3 – Pigeon Creek, Pigeon Lake Outlet

Sampling Date	10/31/2007	5/23/2008	7/24/2008	9/14/2008	5/22/2009	7/22/2009	8/19/2009	8/24/2009	5/26/2010	7/28/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	3	10	4	24	579	36	92	118	98	28	38
E-coli collection date (if different)				9/10/2008	5/29/2009						
Total Phos. (ppm)	0.02	<.01	BDL	0.01	0.05	0.02		0.02	0.16	0.02	0.06
Total Suspended Solids (ppm)	4.4	5	6	12	20	<1		17	24	4	3
D.O.	6.81	9.08	12.63	8.08	7.85	12.02		7.97	6.44	9.39	9.84
pH	8.14	7.70	8.31	7.87	7.43	8.35		7.79	7.23	8.28	8.26
Temp. (c)	13.1	15.4	25.9	21.5	18.4	23.0		24.9	21.1	28.1	23.5
Specific Conductance		617	593	*559	418.3	612		*680	418.5	611	581
Post Rain Event						*			*		
CFM Discharge Estimate	503.35	1607.06	1009.80	1736.86	2334.57	3352.80		497.82	flooding	547.25	626.98
T.S.S. Loading Estimate Kg/day	90.26	327.45	246.90	849.36	1902.77	BDL		344.88	flooding	89.21	76.65
Phos. Loading estimate Kg/day	0.47	BDL	BDL	0.70	2.28	2.73		0.41	flooding	0.45	1.53
Total Nitrate Loading Kg/day	5.74										
oxydation reduction potential (mV)	-104										
B.O.D. (5 day ppm)	5										
Nitrate/Nitrite (ppm)	0.28										
Nitrate (ppm)	0.28										
Nitrite (ppm)	0										

BDL= below detection limit

Table 4. Steuben SWCD stream water quality data from Site 4 – Pigeon, U.S. 20 Bridge, Below junction with Berlien Ditch

Sampling Date	8/19/2009	5/26/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	4920	68	66	158
E-coli collection date (if different)				
Total Phos. (ppm)		0.17	0.06	0.06
Total Suspended Solids (ppm)		24	12	3
D.O.		6.90	6.13	6.98
pH		7.32	8.07	7.98
Temp. (c)		21.8	24.3	24.4
Specific Conductance		431.1	637	611
Post Rain Event		*		
CFM Discharge Estimate		6765.47	1286.61	1140.86
T.S.S. Loading Estimate Kg/day		6616.95	629.18	139.48
Phos. Loading estimate Kg/day		46.87	3.15	2.79

BDL= below detection limit

Table 5. Steuben SWCD stream water quality data from Site 5 – Pigeon Creek, Metz Road

Sampling Date	8/19/2009	5/26/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	14800	120	32	74
E-coli collection date (if different)				
Total Phos. (ppm)		0.16	0.07	0.01
Total Suspended Solids (ppm)		21	10	10
D.O.		6.36	5.57	4.31
pH		7.23	7.84	7.63
Temp. (c)		21.7	24.1	23.3
Specific Conductance		444	655	614
Post Rain Event		*		
CFM Discharge Estimate		6937.57	537.83	542.64
T.S.S. Loading Estimate Kg/day		5937.12	219.18	221.14
Phos. Loading estimate Kg/day		45.24	1.53	2.21

BDL= below detection limit

Table 6. Steuben SWCD stream water quality data from Site 6 – Pigeon Creek between Metz and 275 E

Sampling Date	8/19/2009
E-coli (CFU or colonies/100 ml)	10360
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading Estimate Kg/day	

BDL= below detection limit

Table 7. Steuben SWCD stream water quality data from Site 7 – Pigeon Creek at 275 E

Sampling Date	8/19/2009
E-coli (CFU or colonies/100 ml)	9800
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading estimate Kg/day	

BDL= below detection limit

Table 8. Steuben SWCD stream water quality data from Site 8 – Pigeon Creek at Hanselman

Sampling Date	9/19/2009
E-coli (CFU or colonies/100 ml)	9600
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading estimate Kg/day	

BDL= below detection limit

Table 9. Steuben SWCD stream water quality data from Site 9 – Pigeon Creek between Johnson Ditch and Bill Deller Road

Sampling Date	8/19/2009
E-coli (CFU or colonies/100 ml)	5400
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading estimate Kg/day	

BDL= below detection limit

Table 10. Steuben SWCD stream water quality data from Site 10 – Pigeon Creek downstream of Zabst Ditch

Sampling Date	8/19/2009
E-coli (CFU or colonies/100 ml)	6440
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading Estimate Kg/day	
Total Nitrate Loading Kg/day	
oxydation reduction potential (mV)	
B.O.D. (5 day ppm)	
Nitrate/Nitrite (ppm)	
Nitrate (ppm)	
Nitrite (ppm)	

BDL= below detection limit

Table 11. Steuben SWCD stream water quality data from Site 11 – Pigeon Creek, Bill Deller Road

Sampling Date	10/31/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/19/2009	8/24/2009	5/26/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	n/d	120	530	324	1200	388	7300	466	110	206	820
E-coli collection date (if different)				9/10/2008	5/28/2009	7/29/2009					
Total Phos. (ppm)	0.019	<.01	0.05	0.02	0.06	0.02		0.04	0.22	0.09	0.06
Total Suspended Solids (ppm)	3.6	11	8	48	16	13		21	16	25	5
D.O.	7.59	7.23	6.76	6.69	7.14	7.81		8.10	4.10	5.57	6.57
pH	8.04	7.45	7.84	7.63	7.59	8.13		7.62	7.32	7.86	7.97
Temp. (c)	11.6	14.1	21.6	20.9	18.0	22.8		20.6	21.9	21.7	22.5
Specific Conductance		663	675	*553	482	670		*690	399.4	665	633
Post Rain Event									*		
CFM Discharge Estimate	903.78	2331.45	1109.36	3095.14	4418.52	1143.24		904.96	14940.45	907.26	689.43
T.S.S. Loading Estimate Kg/day	132.59	1045.12	361.67	6054.39	2881.02	605.66		774.46	9741.65	924.32	140.48
Phos. Loading Estimate Kg/day	0.70	BDL	2.26	2.50	10.80	0.93		1.48	133.95	3.33	1.69
Total Nitrate Loading Kg/day	17.31										
oxydation reduction potential (mV)	-99										
B.O.D. (5 day ppm)	3										
Nitrate/Nitrite (ppm)	0.47										
Nitrate (ppm)	0.47										
Nitrite (ppm)	0										

BDL= below detection limit

Table 12. Steuben SWCD stream water quality data from Site 12 – Pigeon Creek, Meridian Road

Sampling Date	10/31/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/19/2009	8/25/2009	5/26/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	n/d	130	642	366	1240	562	7280	684	108	396	880
E-coli collection date (if different)				9/10/2008	5/28/2009	7/29/2009					
Total Phos. (ppm)	0.03	<.01	0.08	0.03	0.06	0.07		0.08	0.18	0.11	0.1
Total Suspended Solids (ppm)	2.8	18	20	49	104	8		44	15	26	15
D.O.	7.57	7.16	6.90	6.55	7.23	7.16		6.56	4.64	5.44	7.00
pH	8.02	7.50	7.83	7.55	7.62	8.01		7.56	7.37	7.84	7.97
Temp. (c)	11.4	14.2	21.6	20.1	17.4	22.3		16.8	22.7	20.8	22.4
Specific Conductance		756	827	*578	509	876		792	462.6	911	862
Post Rain Event									*		
CFM Discharge Estimate	1816.15	3285.46	1438.22	4589.46	4483.74	1591.87		1450.31	18029.40	1978.88	1850.97
T.S.S. Loading Estimate Kg/day	207.23	2410.00	1172.20	16645.63	19003.02	518.97		2600.52	11021.01	2096.73	1131.46
Phos. Loading estimate Kg/day	2.06	BDL	4.69	5.61	10.96	4.54		4.73	132.25	8.87	7.54
Total Nitrate Loading Kg/day	131										
oxydation reduction potential (mV)	-98										
B.O.D. (5 day ppm)	3										
Nitrate/Nitrite (ppm)	1.77										
Nitrate (ppm)	1.77										
Nitrite (ppm)	0										

BDL= below detection limit

Table 13. Steuben SWCD stream water quality data from Site 13 – Pigeon Creek at West 200 South

Sampling Date	8/19/2009
E-coli (CFU or colonies/100 ml)	6080
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading estimate Kg/day	

BDL= below detection limit

Table 14. Steuben SWCD stream water quality data from Site 14 – Pigeon Creek W. Ols US Highway 27

Sampling Date	8/19/2009
E-coli (CFU or colonies/100 ml)	6480
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading estimate Kg/day	

BDL= below detection limit

Table 15. Steuben SWCD stream water quality data from Site 15 – Pigeon Creek, Long Lake Inlet

Sampling Date	10/31/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/19/2009	8/25/2009	5/26/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	238	100	540	388	1120	536	5880	470	100	212	600
E-coli collection date (if different)	11/7/2007			9/10/2008	5/28/2009	7/29/2009					
Total Phos. (ppm)	0.03	<.01	0.09	BDL	0.06	0.04		0.07	0.16	0.10	0.07
Total Suspended Solids (ppm)	1.6	11	12	65	20	10		16	16	19	7
D.O.	8.85	8.13	7.64	7.16	7.85	7.70		7.68	5.80	6.10	7.16
pH	8.06	7.60	7.86	7.46	7.70	7.92		7.56	7.49	7.86	7.97
Temp. (c)	12.1	14.5	21.4	21.1	17.1	21.0		21.2	22.4	22.4	21.6
Specific Conductance		741	806	608	509	856		745	469.9	880	847
Post Rain Event									*		
CFM Discharge Estimate	1304.26	3343.42	1050.60	5609.34	3715.99	1291.98		1034.25	flooding	1852.49	948.87
T.S.S. Loading Estimate Kg/day	85.04	1498.76	513.77	14858.46	3028.68	526.51		1723.54	flooding	1434.36	270.68
Phos. Loading estimate Kg/day	1.51	BDL	3.85	BDL	9.08	2.11		2.95	flooding	7.55	2.71
Total Nitrate Loading Kg/day	89.29										
oxydation reduction potential (mV)	-100										
B.O.D. (5 day ppm)	5										
Nitrate/Nitrite (ppm)	1.68										
Nitrate (ppm)	1.68										
Nitrite (ppm)	0										

BDL= below detection limit

Table 16. Steuben SWCD stream water quality data from Site 16 – Pigeon Creek, Long Lake Outlet

Sampling Date	10/31/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/25/2009	5/27/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	15	10	8	840	20	104	62	206	10	8
E-coli collection date (if different)	11/7/2007			9/15/2008	6/2/2009	7/29/2009				
Total Phos. (ppm)	0.06	<.01	0.03	0.02	0.04	0.02	0.04	0.12	0.04	0.04
Total Suspended Solids (ppm)	3.2	2	30	13	BDL	4	27	8	15	8
D.O.	6.13	9.90	11.00	10.75	8.98	8.10	11.83	5.30	9.86	11.00
pH	7.92	8.00	8.41	8.93	7.82	8.39	8.06	7.40	8.13	8.50
Temp. (c)	13.5	17.1	25.4	21.2	19.3	24.2	21.6	21.7	26.5	25.7
Specific Conductance		656	651	709	485	755	698	455.2	715	677
Post Rain Event								*		
CFM Discharge Estimate	1596.74	4695.72	1173.05	4699.30	ND	1676.25	1566.42	flooding	2298.81	1849.65
T.S.S. Loading Estimate Kg/day	208.23	382.72	1434.13	2489.58	ND	273.24	1723.54	flooding	1405.22	603.02
Phos. Loading estimate Kg/day	3.64	BDL	1.43	3.83	ND	1.37	2.55	flooding	3.75	3.02
Total Nitrate Loading Kg/day	52.71									
oxydation reduction potential (mV)	-95									
B.O.D. (5 day ppm)	6									
Nitrate/Nitrite (ppm)	0.81									
Nitrate (ppm)	0.81									
Nitrite (ppm)	0									

BDL= below detection limit

Table 17. Steuben SWCD stream water quality data from Site 17 – Pigeon Creek, Mud Lake Outlet just west of Long Lake, Johnson Ditch from Ashley

Sampling Date	5/27/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	128	36	300
E-coli collection date (if different)			
Total Phos. (ppm)	0.14	0.05	0.04
Total Suspended Solids (ppm)	10	13	6
D.O.	4.87	7.24	7.13
pH	7.35	7.81	8.06
Temp. (c)	21.5	26.1	23.8
Specific Conductance	475.8	840	728
Post Rain Event	*		
CFM Discharge Estimate	flooding	2968.19	1792.11
T.S.S. Loading Estimate Kg/day	flooding	1572.48	438.19
Phos. Loading estimate Kg/day	flooding	6.05	2.92

BDL= below detection limit

Table 18. Steuben SWCD stream water quality data from Site 18 – Pigeon Creek, Big Bower Lake Inlet

Sampling Date	11/2/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/25/2009	5/27/2010	7/29/2010	8/25/2010
E-coli (CFU or colonies/100 ml)	15	17	72	6	248	200	94	174	104	150
E-coli collection date (if different)				11/26/2008	5/28/2009	7/29/2009				
Total Phos. (ppm)	0.04	<.01	0.04	0.1	0.05	0.02	0.04	0.16	0.06	0.05
Total Suspended Solids (ppm)	3.6	6	12	20	12	3	23	14	11	7
D.O.	4.58	8.87	7.53	7.80	8.12	7.44	9.80	4.85	6.43	7.45
pH	7.87	7.70	7.82	10.19	7.57	7.98	7.82	7.34	7.85	8.03
Temp. (c)	8.5	16.4	25.0	20.7	19.6	24.4	21.5	21.7	26.0	23.5
Specific Conductance		726	683	704	513	781	719	468.7	752	702
Post Rain Event*								*		
CFM Discharge Estimate	1651.69	9414.11	2751.28	3376.52	ND	2660.67	2592.16	flooding	2454.83	2020.12
T.S.S. Loading Estimate Kg/day	242.31	2301.86	1345.44	2752.00	ND	325.29	2429.62	flooding	1100.43	576.27
Phos. Loading estimate Kg/day	2.68	BDL	4.48	13.76	ND	2.17	4.23	flooding	6.00	4.12
Total Nitrate Loading Kg/day	55.19									
oxydation reduction potential (mV)	-90									
B.O.D. (5 day ppm)	4									
Nitrate/Nitrite (ppm)	0.82									
Nitrate (ppm)	0.82									
Nitrite (ppm)	0									

BDL= below detection limit

Table 19. Steuben SWCD stream water quality data from Site 19 – Pigeon Creek, Big Bower Lake Outlet/Golden Lake Inlet

Sampling Date	11/2/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/25/2009	5/27/2010	7/30/2010	8/25/2010
E-coli (CFU or colonies/100 ml)	0	140	30	6	130	94	16	122	26	22
E-coli collection date (if different)				11/26/2008	5/28/2009	7/29/2009				
Total Phos. (ppm)	0.03	<.01	0.05	BDL	0.04	0.04	0.04	0.16	0.04	0.06
Total Suspended Solids (ppm)	3.2	4	13	1	6	<1	22	11	13	11
D.O.	6.42	9.45	10.8	6.41	8.83	11.08	9.65	5.24	8.22	6.45
pH	7.85	7.78	8.22	10.25	7.65	8.26	7.87	7.47	8.04	7.99
Temp. (c)	11.0	17.0	26.8	20.3	20.2	24.3	22.2	22.6	26.3	24.5
Specific Conductance		724	658	710	508	767	711	464.4	751	712
Post Rain Event								*		
CFM Discharge Estimate	2104.95	5720.94	1871.66	6017.44	8582.47	1845.38	2307.81	flooding	2508.24	1417.43
T.S.S. Loading Estimate Kg/day	274.50	932.56	991.56	1471.34	2098.52	BDL	2069.05	flooding	1328.81	635.39
Phos. Loading estimate Kg/day	2.79	BDL	3.81	BDL	13.99	3.01	3.76	flooding	4.09	3.47
Total Nitrate Loading Kg/day	62.62									
oxydation reduction potential (mV)	-90									
B.O.D. (5 day ppm)	6									
Nitrate/Nitrite (ppm)	0.73									
Nitrate (ppm)	0.73									
Nitrite (ppm)	0									

BDL= below detection limit

Table 20. Steuben SWCD stream water quality data from Site 20 – Pigeon Creek, Golden Lake Outlet

Sampling Date	11/2/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/25/2009	5/27/2010	7/30/2010	8/25/2010
E-coli (CFU or colonies/100 ml)	3	<3	8	51	40	44	28	84	52	18
E-coli collection date (if different)				11/26/2008	5/28/2009	7/29/2009				
Total Phos. (ppm)	0.04	<.01	0.03	BDL	0.02	<.01	0.03	0.13	0.03	0.04
Total Suspended Solids (ppm)	4.4	2	4	7	8	<1	15	8	15	14
D.O.	6.55	9.08	13.71	4.12	12.59	8.59	13.03	6.22	10.16	7.06
pH	8.07	7.84	8.55	9.79	8.28	8.22	8.26	7.47	8.12	8.16
Temp. (c)	11.5	17.8	30.0	20.2	21.9	26.4	24.0	22.0	27.1	25.9
Specific Conductance		712	585	639	527	713	675	473.9	683	669
Post Rain Event								*		
CFM Discharge Estimate	2596.36	8345.47	1811.42	4371.76	6906.26	ND	ND	flooding	2584.12	1620.56
T.S.S. Loading Estimate Kg/day	465.55	680.19	295.28	9086.06	2251.55	ND	ND	flooding	1579.62	924.57
Phos. Loading estimate Kg/day	4.03	BDL	2.21	BDL	5.63	ND	ND	flooding	3.16	2.64
Total Nitrate Loading Kg/day	37.03									
oxydation reduction potential (mV)	-100									
B.O.D. (5 day ppm)	5									
Nitrate/Nitrite (ppm)	0.35									
Nitrate (ppm)	0.35									
Nitrite (ppm)	0									

BDL= below detection limit

Table 21. Steuben SWCD stream water quality data from Site 21 – Pigeon Creek, Hogback Lake Inlet

Sampling Date	11/2/2007	5/23/2008	7/29/2008	9/14/2008	5/23/2009	7/24/2009	8/25/2009	5/27/2010	7/30/2010	8/25/2010
E-coli (CFU or colonies/100 ml)	11	3	84	22	48	50	38	128	82	96
E-coli collection date (if different)				10/2/2008	5/28/2009	7/29/2009				
Total Phos. (ppm)	0.04	<.01	0.05	0.05	0.03	0.01	0.03	0.19	0.04	0.04
Total Suspended Solids (ppm)	1.2	3	10	BDL	6	<1	15	9	20	5
D.O.	5.08	9.44	9.72	5.65	11.24	8.70	11.08	5.41	7.64	6.50
pH	7.99	7.83	8.13	7.63	7.95	8.16	8.13	7.37	7.93	8.06
Temp. (c)	10.6	17.3	25.1	15.9	20.3	25.8	23.4	21.7	25.5	24.3
Specific Conductance		711	581	673	512	712	675	476.7	684	670
Post Rain Event								*		
CFM Discharge Estimate	1773.47	6149.28	1863.54	595.57	7563.50	1759.58	2015.38	flooding	2849.12	1273.46
T.S.S. Loading Estimate Kg/day	86.73	751.79	759.43	BDL	1849.37	BDL	1231.96	flooding	2322.15	259.48
Phos. Loading estimate Kg/day	2.90	BDL	3.80	1.21	9.25	0.72	2.46	flooding	4.64	2.08
Total Nitrate Loading Kg/day	29.63									
oxydation reduction potential (mV)	-99									
B.O.D. (5 day ppm)	4									
Nitrate/Nitrite (ppm)	0.41									
Nitrate (ppm)	0.41									
Nitrite (ppm)	0									

BDL= below detection limit

Table 22. Steuben SWCD stream water quality data from Site 22 – Pigeon Creek, Hogback Lake Outlet

Sampling Date	11/2/2007	5/23/2008	7/28/2008	10/2/2008	5/23/2009	7/24/2009	8/25/2009	5/27/2010	7/30/2010	8/25/2010
E-coli (CFU or colonies/100 ml)	1	3	30	18	90	112	14	96	54	10
E-coli collection date (if different)					5/28/2009	7/29/2009				
Total Phos. (ppm)	<.01	<.01	0.04	0.06	0.03	0.04	0.03	0.14	0.04	0.04
Total Suspended Solids (ppm)	4	3	4	BDL	3	5	8	4	9	8
D.O.	8.32	10.93	16.20	5.19	11.66	11.38	11.55	7.43	8.52	7.84
pH	8.49	8.10	8.61	7.57	8.09	8.49	8.16	7.74	8.10	8.17
Temp. (c)	12.2	19	26.6	17.6	23.5	24.9	24.1	22.3	26.8	25.8
Specific Conductance		668	522	306.4	568	622	628	506	610	606
Post Rain Event								*		
CFM Discharge Estimate	2269.32	6613.61	2545.46	539.35	ND	2194.52	ND	flooding	2992.48	2550.94
T.S.S. Loading Estimate Kg/day	369.92	808.55	414.93	BDL	ND	447.16	ND	flooding	1097.55	831.65
Phos. Loading estimate Kg/day	BDL	BDL	4.15	1.32	ND	3.58	ND	flooding	4.88	4.16
Total Nitrate Loading Kg/day	27.74									
oxydation reduction potential (mV)	-122									
B.O.D. (5 day ppm)	6									
Nitrate/Nitrite (ppm)	0.3									
Nitrate (ppm)	0.3									
Nitrite (ppm)	0									

BDL= below detection limit

Table 23. Steuben SWCD stream water quality data from Site 23 – Pigeon Creek at 327

Sampling Date	11/2/2007	5/28/2008	7/29/2008	10/2/2008	5/23/2009	7/29/2009	8/25/2009	5/27/2010	7/30/2010	8/25/2010
E-coli (CFU or colonies/100 ml)	116	86	154	86	740	184	146	88	264	176
E-coli collection date (if different)					5/28/2009					
Total Phos. (ppm)	0.03	<.01	0.02	0.05	0.02	0.02	0.02	0.14	0.04	0.03
Total Suspended Solids (ppm)	0.8	26	6	BDL	6	3	13	14	10	2
D.O.	8.85	8.48	8.69	7.67	9.96	8.23	8.98	6.90	6.25	6.62
pH	8.10	7.77	7.78	7.70	7.86	8.06	7.45	7.77	7.71	7.89
Temp. (c)	11.2	15.8	23.9	15.0	22.5	22.7	22.4	22.3	20.6	21.2
Specific Conductance		677	592	651	550	668	644	521	643	638
Post Rain Event								*		
CFM Discharge Estimate	3696.41	8256.50	3335.60	2888.43	10154.30	3034.33	3914.78	flooding	3657.39	3192.55
T.S.S. Loading Estimate Kg/day	120.51	8748.19	815.60	BDL	2482.85	370.96	2073.96	flooding	1490.46	260.21
Phos. Loading estimate Kg/day	4.50	BDL	2.72	5.89	8.28	2.47	3.19	flooding	5.96	3.90
Total Nitrate Loading Kg/day	109.96									
oxydation reduction potential (mV)	-104									
B.O.D. (5 day ppm)	4									
Nitrate/Nitrite (ppm)	0.73									
Nitrate (ppm)	0.73									
Nitrite (ppm)	0									

BDL= below detection limit

Table 24. Steuben SWCD stream water quality data from Site 43 – Turkey Creek, Tributary to Big Turkey Lake

Sampling Date	7/29/2008	10/6/2008	5/30/2009	7/30/2009	8/27/2009	5/24/2010	7/28/2010	8/23/2010
E-coli (CFU or colonies/100 ml)	132	252	1680	432		228	178	360
E-coli collection date (if different)		10/8/2008	5/28/2009					
Total Phos. (ppm)	0.05	BDL	0.03	0.05	0.05	0.09	0.07	0.09
Total Suspended Solids (ppm)	BDL	BDL	4	<1	7	14	<1	<1
D.O.	7.53	9.65	11.03	7.27	6.61	5.77	5.27	4.66
pH	7.66	7.78	8.06	7.68	7.45	7.47	7.53	7.54
Temp. (c)	25.9	15.1	21.3	18.6	18.9	20.8	23.4	20.4
Specific Conductance	607	651	567	597	508	568	602	619
Post Rain Event					*	*	BDL	
CFM Discharge Estimate	666.77	246.25	1064.15	842.52	1266.26	flooding	801.52	329.03
T.S.S. Loading Estimate Kg/day	BDL	BDL	173.43	BDL	361.22	flooding	2.29	BDL
Phos. Loading estimate Kg/day	1.36	BDL	1.30	1.72	2.58	flooding	BDL	1.21

BDL= below detection limit

Table 25. Steuben SWCD stream water quality data from Site 44 – Pigeon Creek, Fox Lake Outlet

Sampling Date	7/30/2008	10/6/2008	5/30/2009	7/30/2009	8/27/2009	5/24/2010	7/15/2010	8/19/2010
E-coli (CFU or colonies/100 ml)	76	44	16	54	840	12	500	no flow
E-coli collection date (if different)		9/10/2008	5/28/2009					
Total Phos. (ppm)	0.09		BDL	<.01	0.05	0.09	<.01	no flow
Total Suspended Solids (ppm)	BDL		12	6	2	14	4	no flow
D.O.	6.18	no flow	9.79	6.09	4.00	8.57	8.57	no flow
pH	8.05		8.51	7.79	7.90	8.42	8.39	no flow
Temp. (c)	26.2		22.7	18.6	18.6	23.7	30.6	no flow
Specific Conductance	468.9		461.9	482.6	528	488.6	469	no flow
Post Rain Event					*	*	BDL	
CFM Discharge Estimate	14.42	no flow	206.22	3.56	ND	1769.85	43.06	no flow
T.S.S. Loading Estimate Kg/day	BDL	no flow	100.84	0.87	ND	1009.75	7.02	no flow
Phos. Loading estimate Kg/day	0.05	no flow	BDL	BDL	ND	6.49	BDL	no flow

BDL= below detection limit

Table 26. Steuben SWCD stream water quality data from Site 53 – Pigeon Creek, Tributary to West Otter (Between Arrowhead and Otter)

Sampling Date	5/24/2010	7/27/2010	8/20/2010
E-coli (CFU or colonies/100 ml)	116	2280	8300
E-coli collection date (if different)			
Total Phos. (ppm)	0.05	0.12	0.17
Total Suspended Solids (ppm)	10	1	10
D.O.	7.26	5.34	6.17
pH	7.80	7.77	7.95
Temp. (c)	22.1	26.4	21.9
Specific Conductance	440.1	535	521
Post Rain Event	*	0.15	
CFM Discharge Estimate	923.47	31.63	11.91
T.S.S. Loading Estimate Kg/day	376.33	1.29	4.85
Phos. Loading estimate Kg/day	1.88	0.15	0.08

BDL= below detection limit

Table 27. Steuben SWCD stream water quality data from Site 54 – Pigeon Creek, Tributary between Silver and Hogback

Sampling Date	5/24/2010	7/27/2010	8/20/2010
E-coli (CFU or colonies/100 ml)	14	314	124
E-coli collection date (if different)			
Total Phos. (ppm)	0.02	0.01	0.01
Total Suspended Solids (ppm)	9	2	10
D.O.	8.10	6.96	5.96
pH	8.25	8.23	8.08
Temp. (c)	25.1	29.8	26.0
Specific Conductance	457.9	413.6	408.1
Post Rain Event	*	0.05	
CFM Discharge Estimate	678.05	114.81	119.89
T.S.S. Loading Estimate Kg/day	248.69	9.36	48.86
Phos. Loading estimate Kg/day	0.55	0.05	0.05

BDL= below detection limit

Table 28. Steuben SWCD stream water quality data from Site 56 – Pigeon Creek, William Jack Ditch

Sampling Date	7/28/2010	8/17/2010
E-coli (CFU or colonies/100 ml)	860	1400
E-coli collection date (if different)		
Total Phos. (ppm)	0.10	0.11
Total Suspended Solids (ppm)	5	7
D.O.	6.25	7.45
pH	7.75	7.85
Temp. (c)	23.5	21.5
Specific Conductance	774	777
Post Rain Event	0.02	
CFM Discharge Estimate	5.04	4.91
T.S.S. Loading Estimate Kg/day	1.03	1.40
Phos. Loading estimate Kg/day	0.02	0.02

BDL= below detection limit

B.2 Lake data from Indiana's Clean Lakes Program and Volunteer Lake Monitoring Program

These data were used for the in-lake BATHTUB model used for TMDL development. Data in Table 29 were used to estimate phosphorus loading from upstream lakes, as described in *Section 5.2.2 Model Input*. Data in Table 30 and Table 31 are the observed water quality for chlorophyll-*a* and Secchi transparency for the impaired lakes, also used as BATHTUB model input. Total phosphorus data are presented in *Section 3.3 Assessment of Water Quality – Lakes*.

Table 29. Phosphorus data summary for non-impaired lakes used to estimate upstream lake loading for in-lake BATHTUB models

Lake	2008 AUID	Downstream Impaired Lake	Years Data Were Collected	Sample Size (N)	Growing Season Mean [mg/L]	Minimum [mg/L]	Maximum [mg/L]	Standard Error [mg/L]
Big Long	INJ01P1097_00	Little Turkey	1997, 2001-2010	45	0.0267	0.0150	0.0550	0.00335
Big Turkey	INJ01P1102_00	Little Turkey	1982, 1992, 1997, 2002, 2006	7	0.0408	0.0130	0.0770	0.0121
Fox	INJ01P1075_00	Long	1989, 1992, 1997, 2002, 2008	7	0.0195	0.0150	0.0250	0.00240
Gooseneck	INJ01P1084_00	Meserve	1992	1	0.0220	0.0220	0.0220	n/a
McClish	INJ01P1091_00	Lake of the Woods	1989, 1992-1997, 1999-2010	70	0.0327	0.0140	0.0655	0.00293
Pigeon	INJ01P1042_00	Long	1989, 1990, 1992, 1997, 2002, 2009	6	0.0593	0.0330	0.0970	0.0115
Pretty	INJ01P1098_00	Little Turkey	1989, 1993, 1997, 2002, 2006, 2010	6	0.0145	0.0100	0.0210	0.00173
Still	INJ01P1156_00	North Twin	1991, 1993	2	0.109	0.0290	0.189	0.0800

Table 30. Chlorophyll-*a* data summary for impaired lakes

Lake	2008 AUID	Years Data Were Collected	Sample Size (N)	Growing Season Mean [µg/L]	Minimum [µg/L]	Maximum [µg/L]	Standard Error [µg/L]
Fish	INJ01P1133_00	1993, 2000, 2003	3	3.07	1.12	6.17	1.57
Lake of the Woods	INJ01P1093_00	1992-1995, 1997-2002, 2004-2006, 2008-2010	63	3.89	0.375	9.31	0.679
Little Turkey	INJ01P1101_00	1992-2008, 2010	67	6.72	2.58	21.4	1.06
Long	INJ01P1080_00	1992-1999, 2002, 2009, 2010	36	19.2	0.000	30.6	2.50
Meserve	INJ01P1083_00	none	0	n/a	n/a	n/a	n/a
North Twin	INJ01P1157_00	1993, 2000	2	0.650	0.560	32.0	n/a
Royer	INJ01P1132_00	1989, 1993, 2000, 2003	2	4.83	1.25	8.41	3.58

Table 31. Secchi transparency data summary for impaired lakes

Lake	2008 AUID	Years Data Were Collected	Sample Size (N)	Growing Season Mean [m]	Minimum [m]	Maximum [m]	Standard Error [m]
Fish	INJ01P1133_00	1989, 1990, 1992-1994, 1997-2000, 2002, 2003	47	2.19	1.06	3.53	0.637
Lake of the Woods	INJ01P1093_00	1989-1992, 1994-2002, 2004-2010	94	2.12	1.20	2.91	0.520
Little Turkey	INJ01P1101_00	1989-2008, 2010	87	1.51	0.813	2.03	0.347
Long	INJ01P1080_00	1989-1999, 2002, 2009, 2010	85	1.14	0.700	2.00	0.318
Meserve	INJ01P1083_00	1990, 1992	2	3.60	3.30	3.90	0.424
North Twin	INJ01P1157_00	1989, 1993, 2000	3	1.97	1.70	2.40	0.379
Royer	INJ01P1132_00	1989-1994, 1997-2000, 2002, 2003	35	1.93	0.800	3.96	0.926

APPENDIX C: PIGEON RIVER WATERSHED LAKE WATER QUALITY INFORMATION

Since IDEM is in the rulemaking process for a phosphorus standard in lakes, lake TMDLs were not developed as part of this document, but the information gathered for the Pigeon River watershed lakes and lake impairments has been compiled here.

Lake data for the analysis were gathered from Indiana's Clean Lakes Program and Volunteer Lake Monitoring Program. Data were reviewed for consistency with requirements for secondary data as described in the *Pigeon River Watershed TMDL QAPP*. Data were used in calibration of in-lake models and for estimates of reductions needed to meet the lake TMDLs. Five of the lakes are impaired for biotic communities (IBC) and phosphorus has been identified as the pollutant of concern. Two of the lakes have been identified as impaired due to phosphorus alone. A quantitative phosphorus loading analysis and a soil erosion analysis was conducted for each impaired lake's watershed.

Loadings were determined for each impaired lake based on in-lake modeling that identified the phosphorus load that meets the in-lake phosphorus target. Table EX - 1 summarizes the lake watershed for each HUC 12, the watershed area, impairing parameter, and required percent reduction for each impairment.

Table EX - 1. Total phosphorus TMDL summary for impaired lake watersheds

Lake Watershed	Watershed Area [acres]	Total PhosphorusL [pounds per year]	Percent Reduction to Meet Target[1]
Fish	3,525	26	0%
Lake of the Woods	2,413	6.2	30%
Little Turkey	4,870	14	40%
Long	23,520	24	67%
Meserve	77	0.21	8.5%
North Twin	701	1.5	36%
Royer	3,598	9.7	21%

[1] Calculated based on the difference between the phosphorus load that meets the in-lake phosphorus target (growing season mean of 0.03 mg/L) and the existing phosphorus load

Error! Reference source not found. and **Error! Reference source not found.**, and for the watersheds to the seven impaired lakes.

Waterbody	2010 AUID	Impairment			
		E. coli	IBC[1]	Total P	Total N
LONG LAKE	[3]INJ01P1080_00	no	no	yes	no
MESERVE LAKE	[3]INJ01P1083_00	no	yes	yes	no
LAKE OF THE WOODS	[3]INJ01P1093_00	no	yes	yes	no
LITTLE TURKEY LAKE	[3]INJ01P1101_00	no	no	yes	no
ROYER LAKE	[3]INJ01P1132_00	no	yes	yes	no
FISH LAKE	[3]INJ01P1133_00	no	yes	yes	no
NORTH TWIN LAKE	[3]INJ01P1157_00	no	yes	yes	no

[1]IBC – Impaired Biotic Community
[2] The waterbodies Pigeon River and Ontario Mill Pond Inlet are both listed as AUID INJ01B3_02
[3] 2008 AUI

Lakes Criteria

There are currently no Indiana numeric criteria for phosphorus concentration within lakes, although they are currently under development. A growing season (May 1 through September 30) mean phosphorus concentration of 0.03 mg/L will be used as the numeric target for the impaired lakes in the Pigeon River Watershed; this concentration falls within the range of numeric criteria being considered for phosphorus concentrations. The State of Michigan has a narrative standard for total phosphorus, but not a numeric target. The narrative standard reads,

> (Part 1) Consistent with Great Lakes protection, phosphorus which is or may readily become available as a plant nutrient shall be controlled from point source discharges to achieve 1 milligram per liter of total phosphorus as a maximum monthly average effluent concentration unless other limits, either higher or lower, are deemed necessary and appropriate by the department. (Part 2) In addition to the protection provided under subrule (1) of this rule, nutrients shall be limited to the extent necessary to prevent stimulation of growths of aquatic rooter, attached, suspended, and floating plants, fungi or bacteria which are or may become injurious to the designated uses of the surface waters of the state. [Rule 323.1060 Plant Nutrients. Rule 60.]

A.1 Assessment of Water Quality – Lakes

Total phosphorus data for the impaired lakes are summarized in this section of the report. Phosphorus data is summarized in Table 30 on page 28. Appendix B.2 includes a summary of chlorophyll-*a* and Secchi transparency data, which were also used for lake modeling (see Section A.1.6). Appendix B.1 includes additional secondary data for streams provided by the Steuben SWCD. Monitoring locations located near lake outlets were reviewed for consistency with the TMDL.

Table 30 provides a summary of available lake total phosphorus data. These data were collected through Indiana's Clean Lakes Program and Volunteer Lake Monitoring Program[i] and were used in lake model calibration and estimates of the reductions needed to meet the lake TMDLs (addressed in the individual lake TMDL sections (Section B)).

Table 32. Total phosphorus data summary for lakes

Lake	2008 AUID	Years Data Were Collected	Sample Size (N)	Growing Season Mean [mg/L]	Minimum [mg/L]	Maximum [mg/L]	Standard Error [mg/L]
Fish	INJ01P1133_00	1989, 1993, 2000, 2003	4	0.0195	0.0150	0.0250	0.00240
Lake of the Woods	INJ01P1093_00	1989, 1992-2002, 2004-2006, 2008-2010	69	0.0359	0.0175	0.0770	0.00362
Little Turkey	INJ01P1101_00	1989, 1992-2008, 2010	73	0.0422	0.0150	0.0755	0.00331
Long	INJ01P1080_00	1989, 1990, 1992-1999, 2002, 2009, 2010	37	0.0567	0.0200	0.0913	0.00592
Meserve	INJ01P1083_00	1990, 1992	2	0.0340	0.0100	0.0580	0.0240
North Twin	INJ01P1157_00	1989, 1993, 2000	3	0.0403	0.0100	0.0860	0.0232
Royer	INJ01P1132_00	1993, 2000, 2003	4	0.0340	0.0130	0.0450	0.00715

[1] Data provided on IDEM Clean Lakes Program website. Data were reviewed for consistency with requirements for secondary data as described in the Pigeon River Watershed TMDL QAPP.

A.1.1 Source Characterization

A.1.2 Runoff from other land uses

Land uses other than agriculture are also sources of phosphorus and nitrogen. Residential and commercial properties may use fertilizer containing phosphorus and nitrogen, and most land uses result in some level of erosion of sediments carrying phosphorus. For example, areas with maintained lawns along waterbodies, such as are present around Golden Lake, West Otter Lake, and Long Lake (Steuben SWCD and Steuben County 2006), may act as sources of nutrients if lawn fertilizers are used or if soil erosion occurs along the shoreline. Impervious surfaces further act as a conduit to transport sediment and associated nutrients to nearby waterbodies. These sources of nutrients are incorporated into the modeling completed for this study.

A.1.3 Stream Degradation

Suspended solids and phosphorus can increase in streams due to bank destabilization (e.g. from removal of upland or riparian vegetation or livestock access). Livestock with access to stream environments may cause streambank disturbance and erosion and may resuspend particles that had settled on the stream bottom. Phosphorus adsorbs to sediment particles and often travels through aquatic systems attached to suspended solids. Internally, increases in suspended solids can produce more scouring, introducing additional suspended solids and phosphorus. The sites impacted and the extents of damage depend on stream magnitude, gradient, and whether the site is erosional or depositional.

Many streams in the Pigeon River Watershed are managed as regulated drainage systems and have likely been impacted in the past by straightening and dredging activities. Streambank erosion has been identified in locations along Pigeon Creek, particularly downstream of Hogback Lake and upstream of Long Lake (Steuben SWCD and Steuben County 2006). The following specific areas of sedimentation were noted in the 2006 report: incised channel reaches downstream of Hogback Lake, along Golden Lake Road, at the entrance to Hogback Lake, between Long Lake and Little Bower Lake, and upstream of County Road 150 West (Steuben SWCD and Steuben County 2006).

A.1.4 Soil Erosion

Soil erosion is a source of particulate phosphorus to waterbodies. The Revised Universal Soil Loss Equation (RUSLE) was used as a tool to predict soil erosion in the watersheds of the impaired lakes and for the Mud Creek-Pigeon Creek HUC 12 watershed (040500011002). This equation takes into account slope, soil type and land use to estimate erosion in tons/ac-year. The strength of this tool is that it can be used to target erosion prone areas; however, the tool does not accurately predict sediment yield because much of the soil loss predicted by this equation settles out in flatter or more vegetated areas before leaving a field. **Error! Reference source not found.** shows the parameters defined and data sources used in the evaluation.

Parameter	Defining GIS Layer	Calculation Notes	Description
R	Set as Constant	Defined from figure on page 251 in *Design hydrology and sedimentology for small catchments* (Haan et al. 1994), the 100 isocline transverses the middle of the watershed	Rainfall/runoff factor
K	County Soil Survey	Varies by soil type; value is listed in soil survey; soil types without listed K values were given a median erosivity value of 0.24	Soil erodibility factor
L	Set as Constant	Assume length = to test plot length of 72.6 ft, L = 1	Slope length factor
S	1.5 meter DEM	S = 10.8 sin (theta) + 0.03 if sin (theta) <0.09, S=16.8sin (theta) - 0.50 if sin(theta) >=0.09	Slope steepness factor
C	NLCD Landcover	Defined from tables on 266-267 *Design hydrology and sedimentology for small catchments* (Haan et al. 1994), Book values of C for different land covers	Cover and management factor
P	Set as Constant	Data not available at scale and resolution necessary. Set conservation factor to 0.5.	Supporting conservation practice factor

Results are presented in the lake TMDL discussions in Section B. Average soil loss ranges from zero to 64, representing a range of soil erosion potential, from lowest to highest in tons/ac-year.

Impaired Lakes

In addition to assessing the pollutant sources as described in Section **Error! Reference source not found.**, a quantitative phosphorus loading analysis was conducted for each lake. External phosphorus loading to lakes was estimated using:

1) average annual runoff depths from the USGS national dataset (Gerbert et al. 1987),
2) monitoring data from upstream lakes,
3) for the direct watershed, export coefficients based on land use and adjusted for the following watershed characteristics, as applicable: CSOs, SSOs, wastewater treatment plants, CFOs, and septic systems.

Internal (in-lake) phosphorus sources include phosphorus released from sediment due to low oxygen, phosphorus released from sediment due to physical disturbance by rough fish, and phosphorus released during the senescence of curly-leaf pondweed, which occurs during the growing season. Internal phosphorus loading will not be estimated because these data are unavailable. Internal loading is included implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail).

A.1.5 Direct Watershed Runoff

<u>Export Coefficients</u>

Direct watershed runoff was estimated using phosphorus export coefficients. Export coefficients are used to model nutrient export from a watershed in the absence of sufficient monitoring data from the watershed. Land cover data were obtained from the 2001 National Land Cover Dataset (NLCD). Each land cover category was assigned an export coefficient, which serves to estimate the phosphorus export from watershed runoff. Export coefficients were obtained from available, relevant literature (Boelter and Verry 1977; Burton and Pitt 2002; Heiskary and Wilson 1994; King et al. 2001; Kunimatsu et al. 1999; Lee

2003; Lee and Pilgrim 2003; Loehr 1974; Marsalek 1978; McDowell and Omernik 1977; Menzel et al. 1978; Mulla et al. 2002; Olness et al. 1980; Rast and Lee 1983; Reckhow et al. 1980; Robertson 1996; Sonzogni et al. 1980; Timmons and Holt 1977; U.S. EPA 1999; U.S. EPA 2001; Uttormark et al. 1974).

Table 33 identifies the export coefficients assigned to each land use category. Average export coefficients range from 0 lb/ac-yr from wetlands (representing a net zero phosphorus load assuming an equal potential for both source and sink conditions) to 1.5 lb/ac-yr from cultivated crops and barren land. Forests have an estimated average phosphorus export of 0.1 lb/ac-yr. Export coefficients for different land covers take into account management practices that occurred on the sites in the literature datasets. For example, the export coefficient for cultivated crops and developed areas includes phosphorus export due to fertilizers and manure applied to land of that cover type. The lower-than-average and higher-than-average export coefficients are reflective of variations in the landscape including, but not limited to, land management practices. Average values were used in most cases. However, data from CFOs and septic systems were used to adjust export coefficients to the higher-than-average export coefficient.

CFO permits are issued by the state and have at least 300 cattle, 500 horses, 600 swine or sheep, or 30,000 fowl, such as chickens, turkeys, or other poultry. CFOs are zero discharge facilities. However, IDEM assumes that land application of manure occurs within a five-mile radius of each CFO on land covers categorized as *cultivated crops* and *hay/pasture*. All direct lake watersheds are within the five-mile radius of at least one CFO. Five direct lake watersheds are within the five-mile radius of six or more CFOs. Accounting for both the number of CFOs within a five-mile radius of the direct watershed and the area of the direct watershed, Long Lake was determined to have average phosphorus export from land covers categorized as *cultivated crops* and *hay/pasture*, and Fish, Lake of the Woods, Little Turkey, Meserve, North Twin, and Royer Lakes were estimated to have higher-than-average phosphorus export from *cultivated crops* and *hay/pasture* due to an estimated higher-than-average land application of manure.

Septic systems from homes within 500 feet of the shores of impaired lakes are assumed to contribute higher-than-average phosphorus to the lake as compared to septic systems in more remote areas of the direct watershed. Homes within 500 feet of the lake are mostly characterized by *developed, low intensity* and *developed, open space* land covers. The areas of *developed, low intensity* and *developed, open space* land covers within 500 feet of the lake were divided by the coverage of those land covers within the entire direct watershed. For each lake, the calculated percent area of *developed, low intensity* and *developed, open space* land covers existing within 500 feet of the shore was assigned a higher-than-average export coefficient. All other *developed, low intensity* and *developed, open space* land covers in the direct watersheds were assigned average export coefficients.

Table 33. TP export coefficients by NLCD land cover category

Land Cover	Phosphorus Export [lb/ac-yr]		
	Lower-than-Average	Average	Higher-than-Average
Barren Land[1]	0.8	1.5	2.0
Cultivated Crops[2]	0.8	1.5	2.0
Deciduous Forest	0.05	0.1	0.2
Developed, Open Space[2,3]	0.3	0.5	0.9
Developed, High Intensity	0.7	1.0	1.3
Developed, Medium Intensity	0.4	0.8	1.2
Developed, Low Intensity[2]	0.3	0.5	0.9
Emergent Herbaceous Wetlands	0	0	0
Evergreen Forest	0.05	0.1	0.15
Grassland/Herbaceous	0.09	0.1	0.2

Land Cover	Phosphorus Export [lb/ac-yr]		
	Lower-than-Average	Average	Higher-than-Average
Hay/Pasture[2]	0.4	0.7	1.3
Mixed Forest	0.05	0.1	0.2
Open Water	0	0	0
Shrub/Scrub	0.09	0.1	0.2
Woody Wetlands	0	0	0

[1] NLCD metadata: *Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.*
[2] Land covers for which export coefficients other than the average were used in the direct watershed runoff estimates of some lakes.
[3] NLCD metadata: *Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes*.

Point Sources

The direct watershed of Long Lake has one wastewater treatment plant (Angola WWTP, IN0021296) that discharges to surface waters. Trans Guard Industries WWTP (INP000137) discharges to the Angola WWTP, so it was not accounted for as a separate point source. Average annual loading for Angola WWTP was estimated based on average annual flows derived for the flow duration analysis. Average annual flows were used for the same time period for which in-lake phosphorus monitoring data was gathered for in-lake modeling (1989-2010) and the permit limit of 1 mg/L, discharges above which require a degree of reduction in phosphorus.

Angola WWTP has two CSO locations within the direct watershed of Long Lake. Average annual loading for the CSOs were estimated through the use of discharge monitoring report data available from 2008-2010. The in-lake modeling time period (1989-2010) begins earlier than the period for which CSO monitoring data is available. It is possible that CSO flows in the past (prior to significant efforts to manage CSOs) had greater volumes.

Point sources that discharge to upstream lakes are accounted for through the upstream lakes loading analysis described in Section A.1.6.

A.1.6 Developing Loads

A.1.7 Calibration and Validation of In-Lake BATHTUB Models

In-lake BATHTUB models (Version 9.1) were developed for each of the seven impaired lakes (seven impaired for phosphorus and five also having impaired biotic communities) to link phosphorus loads with in-lake water quality. BATHTUB, a publicly available model, was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). It has been used successfully in many lake studies throughout the United States. BATHTUB is limited to steady-state annual or seasonal time steps and predicts a lake's growing season (May 1 through September 30) mean surface water quality. These time-scales are appropriate because watershed phosphorus loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. BATHTUB can be easily calibrated to monitoring data and takes into account the effects of non-algal turbidity on lake transparency and responses of algae to phosphorus. It has built-in statistical calculations that account for data variability and provides a means for estimating confidence in model predictions. The heart of BATHTUB is a mass-balance phosphorus model that accounts for water and phosphorus inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and (if appropriate) groundwater. The model accounts for outputs through the lake outlet, groundwater (if appropriate), water loss via evaporation, and phosphorus sedimentation and retention in the lake sediments.

Due to the lack of detailed annual loading and water balance data, the models are considered to represent long term average conditions. Phosphorus loads from direct watershed runoff (see Section A.1.5) and upstream lakes (described in *Model Input - Tributary Data: Flow Rate and Phosphorus Concentration*) were used as inputs to the BATHTUB in-lake models. The models were calibrated to existing water quality data, and then used to determine the phosphorus loading capacity of each lake.

<u>System Representation in Model</u>

In typical applications of BATHTUB, lake and reservoir systems are represented by a set of segments and tributaries. Segments are the basins (lakes, reservoirs, etc.) or portions of basins for which water quality parameters are being estimated, and tributaries are the defined inputs of flow and pollutant loading to a particular segment. Loading from upstream waterbodies can be lumped as a single tributary input or as additional tributary inputs.

Under normal use, internal loading is not represented explicitly in BATHTUB. An average rate of internal loading is implicit in BATHTUB since the model is based on empirical data. The model provides an option to include an additional load identified as an internal load if circumstances warrant, but it is generally not recommended. In the lake models for the Pigeon River TMDL calculations, adjustments to internal loading were not necessary for model calibration.

<u>Model Input</u>

The input required to run the BATHTUB model includes watershed and lake geometry information, climate data, and water quality and flow data for runoff contributing to the lake. Observed lake water quality data is also entered into the BATHTUB program in order to facilitate model verification and calibration.

Watershed Delineation

Lake watersheds were delineated based on a 30-m resolution (resampled to 10-m) digital elevation model (DEM) (a regularly spaced grid of elevation points), digital representation of the stream network as defined by the National Hydrography Dataset (NHD)[1] at the 1:24,000-scale, and the NHD watershed boundary dataset. The web-based tool used for delineation was the U.S. Geological Survey (USGS) StreamStats. StreamStats is a Geographic Information System (GIS) application created by the USGS, in cooperation with Environmental Systems Research Institute, Inc. (ESRI). StreamStats is based on ESRI's ArcHydro data model and associated tools. StreamStats was designed so that each state in the U.S. would be implemented as a separate application, with a reliance on local partnerships to fund the individual applications. StreamStats for Indiana was developed in cooperation with the Indiana Department of Natural Resources (IN-DNR). Since the DEM for Indiana has been enhanced by a process that ensures conformity with the existing NHD watershed boundary dataset, delineations obtained form StreamStats are considered to be of greater accuracy than delineations obtained from a standard DEM. Watershed delineations were smoothed and checked for quality against 5-foot DEM and 10-foot topography datasets available through the Indiana Spatial Data Portal.

Watersheds were delineated for impaired lakes as well as adjacent upstream lake(s). Watersheds were delineated for upstream lakes in order to estimate loading from the upstream lake(s) to the impaired lake, which is described in *Model Input - Tributary Data: Flow Rate and Phosphorus Concentration*.

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[1] The NHD was developed cooperatively by the USGS and the U.S. EPA.

Precipitation and Evaporation
Estimates of average annual precipitation were provided by the USDA/NRCS National Cartography & Geospatial Center based on the years 1971-2000. Average annual evaporation was obtained from NOAA Technical Report 33 based on the years 1956-1970.

Atmospheric Deposition
Average phosphorus atmospheric deposition loading rates are provided through BATHTUB and were applied over each lake's surface area.

Segment Data: Lake Morphometry and Observed Water Quality
Lake morphometry data were gathered from the IN-DNR. Shapefiles were provided from the IN-DNR for Little Turkey and Meserve Lakes based on data collected on July 31, 2007 and July 8, 2009, respectively. Morphometry data for the other five lakes were based on hydrographic surveys conducted in the 1950s published by the IN-DNR and prepared cooperatively by the U.S. Geological Survey (USGS), Water Resources Division. Observed water quality input model was based on growing season means (May 1 through September 30) of total phosphorus, chlorophyll-*a*, and Secchi transparency. The available data and the period of record for total phosphorus can be found in Table 30. For a given lake, the datasets for chlorophyll-*a* and Secchi transparency were from within the same time period as that of total phosphorus. Due to water quality data from Indiana's Volunteer Lake Monitoring Program, the total records for Secchi transparency tended to be more extensive than for total phosphorus and chlorophyll-*a*. No chlorophyll-*a* measurements were taken for Meserve Lake and, therefore, the Meserve Lake model was not calibrated for this parameter. Appendix B.2 includes a summary of chlorophyll-*a* and Secchi transparency data for impaired lakes (see Section A.1.6).

Tributary Data: Flow Rate and Phosphorus Concentration
External phosphorus loading was compiled into the model tributary inputs. Watershed phosphorus sources consist of the average annual direct watershed runoff as estimated using the export coefficient method described in Section A.1.5 and upstream lake loading.

Little Turkey, North Twin, Lake of the Woods, and Meserve Lakes have upstream lakes that were accounted for explicitly in BATHTUB. In-lake phosphorus data were available for all significant upstream lakes (see Appendix B.2 for a summary of available data), and they are mapped in the individual lake summaries (see Section B). Long-term average phosphorus concentrations were multiplied by average annual runoff depths provided in the USGS national dataset based on the time period from 1951-1980 (Gerbert et al. 1987).

Chlorophyll-Secchi Coefficient
Among the empirical model parameters is non-algal turbidity, a term that reflects turbidity due to the presence of color and inorganic solids in the water column. This parameter uses the chlorophyll-Secchi coefficient, which is the ratio of the inverse of Secchi transparency (the inverse being proportional to the light extinction coefficient) to the chlorophyll-*a* concentration. The default coefficient in BATHTUB (0.025 m^2/mg), which was calibrated to United States Army Corps of Engineers reservoir data, was used.

<u>Selection of Equations</u>

BATHTUB allows choice among several different mass balance phosphorus models. The phosphorus model that best predicted the in-lake TP concentration was selected (Table 34). For other parameters, the default model selections (chlorophyll-*a* model based on phosphorus, light, and flushing; transparency model based on chlorophyll-*a* and turbidity) were used.

Table 34. Selection of in-lake model (BATHTUB) equations

Lake	BATHTUB Phosphorus Model
Fish	Second-Order, Available P
Lake of the Woods	Second-Order, Fixed
Little Turkey	Canfield-Bachman, Reservoirs
Long	Second-Order, Available P
Meserve	Vollenweider (1976)
North Twin	Second-Order, Fixed
Royer	Second-Order, Fixed

Model Calibration

For all lake models, calibration coefficients were then modified so that the predicted values of phosphorus, chlorophyll-*a*, and Secchi transparency matched the observed values. Matches were made to the nearest whole number for phosphorus and chlorophyll-*a* concentrations (µg/L), and to the nearest tenth of a meter for Secchi transparencies. Since chlorophyll-*a* concentrations were not available for Meserve Lake, the Meserve Lake model was not calibrated to chlorophyll-*a*.

A.1.8 Lake Loading Analysis Using BATHTUB

The loading capacity of each lake is the TMDL. The goal of the lake loading analysis is to identify the phosphorus load that meets the in-lake phosphorus target (growing season mean of 0.03 mg/L) and the required reduction in existing phosphorus load to meet the target.

With calibrated existing conditions models completed for the lakes, reductions in phosphorus loading were simulated in order to estimate the effects on lake water quality. The phosphorus concentrations associated with tributaries of the calibrated existing conditions model were reduced until the model indicated that the in-lake phosphorus target was met. Loads from the models that meet the standard were compared to the loads from the existing conditions models; this process determined the amount of load reduction required for each lake.

The TMDLs were determined in terms of annual loads. In-lake water quality models predict growing season averages of water quality parameters based on annual loads. The annual loads were converted to daily loads by dividing the annual loads by 365.

- There are uncertainties in predicting lake phosphorus loads and predicting how lakes respond to changes in phosphorus loading.

B LAKE SUMMARY OF DATA AND ALLOCATIONS

Fish Lake

Physical Characteristics

Fish Lake (Table 35) is located in LaGrange County (Figure 18). Royer Lake, also impaired, discharges to Fish Lake. Highly erodible soils in the drainage area west of Fish Lake show a significant potential for field erosion (Figure 19). The east edge of the drainage area also contains a combination of steep slopes and erodible soils although delivery of these soils to the lake is probably much lower than the areas closer to the lake.

Table 35. Fish Lake characteristics

Characteristic	Value	Source
Lake total surface area (ac)	100	USGS National Hydrography Dataset
Lake volume (ac-ft)	4055	Indiana DNR August 1956 hydrographic survey prepared cooperatively by the USGS
Mean depth (ft)	41	Calculated (lake area / lake volume)
Maximum depth (ft)	78	Indiana DNR August 1956 hydrographic survey prepared cooperatively by the USGS
Drainage area (acres)	7211	USGS Indiana StreamStats application & EOR
Watershed area: lake area	72	Calculated (watershed area / lake area)
Upstream lakes*	Royer	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported 'Drainage area' in this table.

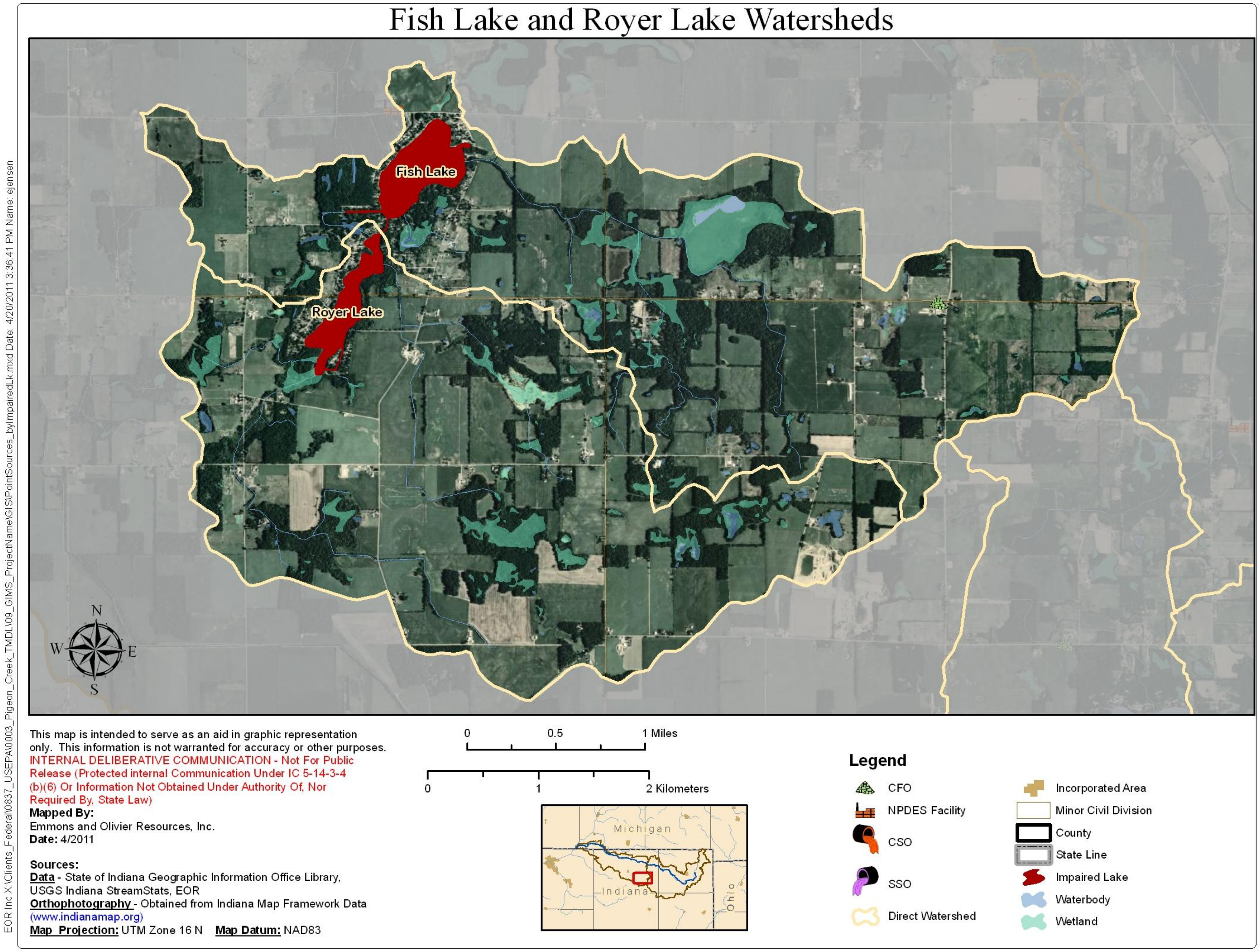

Figure 18. Fish and Royer Lake Watersheds

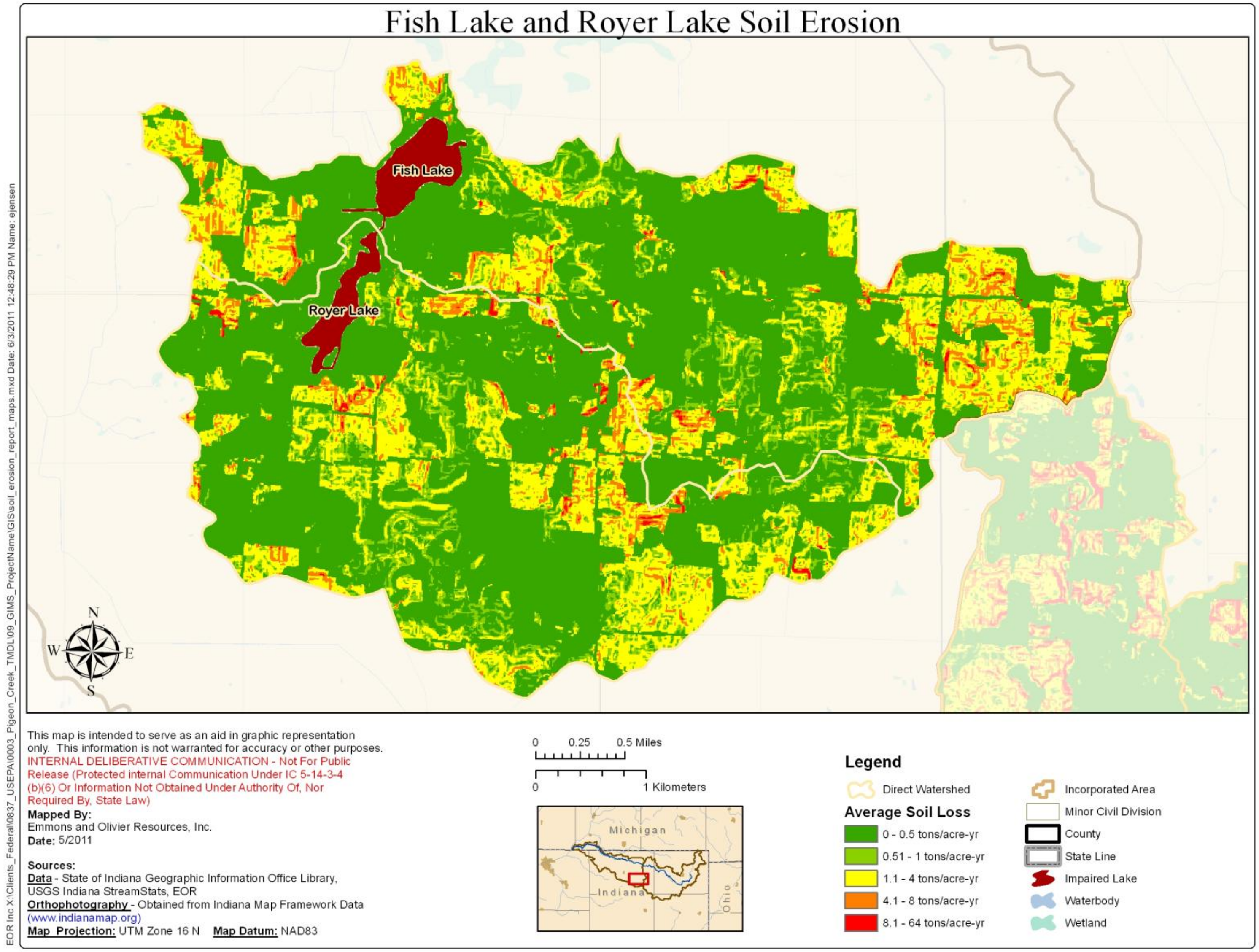

Figure 19. Soil erosion characteristics in Fish and Royer Lake Watersheds

Land Cover

At present, the dominant land cover in the Fish Lake watershed is cultivated crops (Table 36).

Table 36. Fish Lake Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage		Entire Drainage (including Royer Lake watershed and lake)	
	Acres	% of Watershed	Acres	% of Watershed
Barren Land	-	-	-	-
Cultivated Crops	1759	50%	3560	49%
Deciduous Forest	215	6.1%	371	5.1%
Developed, Low Intensity	49	1.4%	105	1.5%
Developed, Medium Intensity	10	0.29%	13	0.18%
Developed, High Intensity	-	-	-	-
Developed, Open Space	174	4.9%	311	4.3%
Emergent Herbaceous Wetlands	58	1.6%	64	0.89%
Evergreen Forest	13	0.37%	44	0.61%
Hay/Pasture	446	13%	999	14%
Herbaceous	55	1.6%	78	1.1%
Mixed Forest	1.2	0.033%	1.2	0.016%
Open Water	16	0.44%	81	1.1%
Shrub/Scrub	-	-	-	-
Woody Wetlands	743	21%	1584	22%
Total*	**3539**	**100%**	**7212**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Water Quality

Phosphorus monitoring data are available from 1989, 1993, 2000, and 2003. The lake is currently meeting lake water quality standards for TP (Table 37). Table 30 shows additional detail regarding the phosphorus monitoring data available for Fish Lake.

Table 37. Fish Lake surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.020	0.030
Chlor-a (µg/L)	3.1	none
Secchi transparency (m)	2.2	none

Existing Phosphorus Loading

<u>Watershed Phosphorus Loading</u>

The contributing watershed to Fish Lake includes watershed runoff coming from the direct drainage to the lake and drainage from Royer Lake. It is estimated that Fish Lake receives 4577 pounds of phosphorus annually from external sources (Table 38). Approximately 7% of the phosphorus is coming from Royer Lake.

Table 38. Fish Lake external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	4238	93%
Upstream Lake Loading (Royer Lake)	339	7.4%
Total*	**4577**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Internal Phosphorus Loading

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in Fish Lake is higher than the average of the field datasets used for development of the BATHTUB model.

Fish Lake monitoring data indicate that internal loading is a source of phosphorus to the lake. Dissolved oxygen concentrations were below 1 mg/l at a depth of 18 meters and below. At these low dissolved oxygen concentrations, phosphorus is released from the sediment to the hypolimnion and mixes with the surface water when the water column mixes during fall turnover. Fish Lake's monitoring data during thermal stratification is evidence of this process occurring; during the two July days that were monitored, hypolimnetic (bottom water) soluble and total phosphorus concentrations were higher than epilimnetic (surface water) concentrations (Table 39). This phosphorus is then available for algal uptake and growth during the following growing season.

Table 39. Fish Lake water quality data from Clean Lakes Program Data Summary

Date	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
	Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
7/10/2000	0.01	0.06	0.03	0.06
7/01/2003	0.01	0.05	0.02	0.06

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l

Clean Lakes Program data summaries indicate that blue-green algal dominance was high (63-97%), and the zooplankton community was skewed towards smaller zooplankton (rotifers, as opposed to cladocera) that have less ability to control algal densities.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Fish Lake is 9381 lb/yr, to be split among allocations according to Table 40. The lake is currently meeting the TMDL goals. There are no NPDES-permitted sources in the Fish Lake watershed. There is one CFO (#3622) in the Fish Lake watershed; CFOs are zero discharge facilities and receive a LA of zero.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 40. Fish Lake allocation summary

Allocation*	lb/yr	lb/day
TMDL	9381	26
MOS	9938	2.6
WLA	0.0	0.0
LA	8443	23

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Implementation Strategy

Fish Lake is in the East Fly Creek HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the Fish Lake watershed. The majority of the land use in the watershed is agricultural in nature, and there is one CFO in the watershed. The pollutant sources and management practices for the East Fly Creek HUC 12 watershed (**Error! Reference source not found.**) apply to the Fish Lake watershed, in addition to the other sources and implementation approaches identified in Table 41. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 41. Implementation approaches to addresses sources in Fish Lake watershed

Type	Source Summary	Implementation Section
Soil Erosion	Highly erodible soils in the drainage area west of Fish Lake and in the east edge of the drainage area (see Figure 19 on page 37)	**Error! Reference source not found.**
Internal Loading	Phosphorus release due to anoxic hypolimnion	B.1.1
Internal Loading	Potential imbalanced in-lake ecological interactions	B.1.1
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**

<u>Potential Priority Implementation Areas</u>

Fish Lake currently meets water quality standards. However, water quality improvements are still possible, and should focus on the following:

- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the CFO, land application of manure and other fertilizers, and droppings from working horses.
- Potential field erosion in the drainage area west of Fish Lake.

Lake of the Woods

Physical Characteristics

Lake of the Woods (Table 42) is located in LaGrange and Steuben Counties (Figure 20). McClish Lake discharges to Lake of the Woods. Highly erodible soils are located in the southern half of the Lake of the Woods drainage area (Figure 21).

Table 42. Lake of the Woods characteristics

Characteristic	Value	Source
Lake total surface area (ac)	117	USGS National Hydrography Dataset
Lake volume (ac-ft)	4,680	Calculated (surface area x mean depth)

Mean depth (ft)	40	Calculated based on Indiana DNR August 1958 hydrographic survey prepared cooperatively by the USGS
Maximum depth (ft)	84	Indiana DNR August 1958 hydrographic survey prepared cooperatively by the USGS
Drainage area (acres)	2,422	USGS Indiana StreamStats application & EOR
Watershed area: lake area	21	Calculated (watershed area / lake area)
Upstream lakes*	McClish	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported 'Drainage area' in this table.

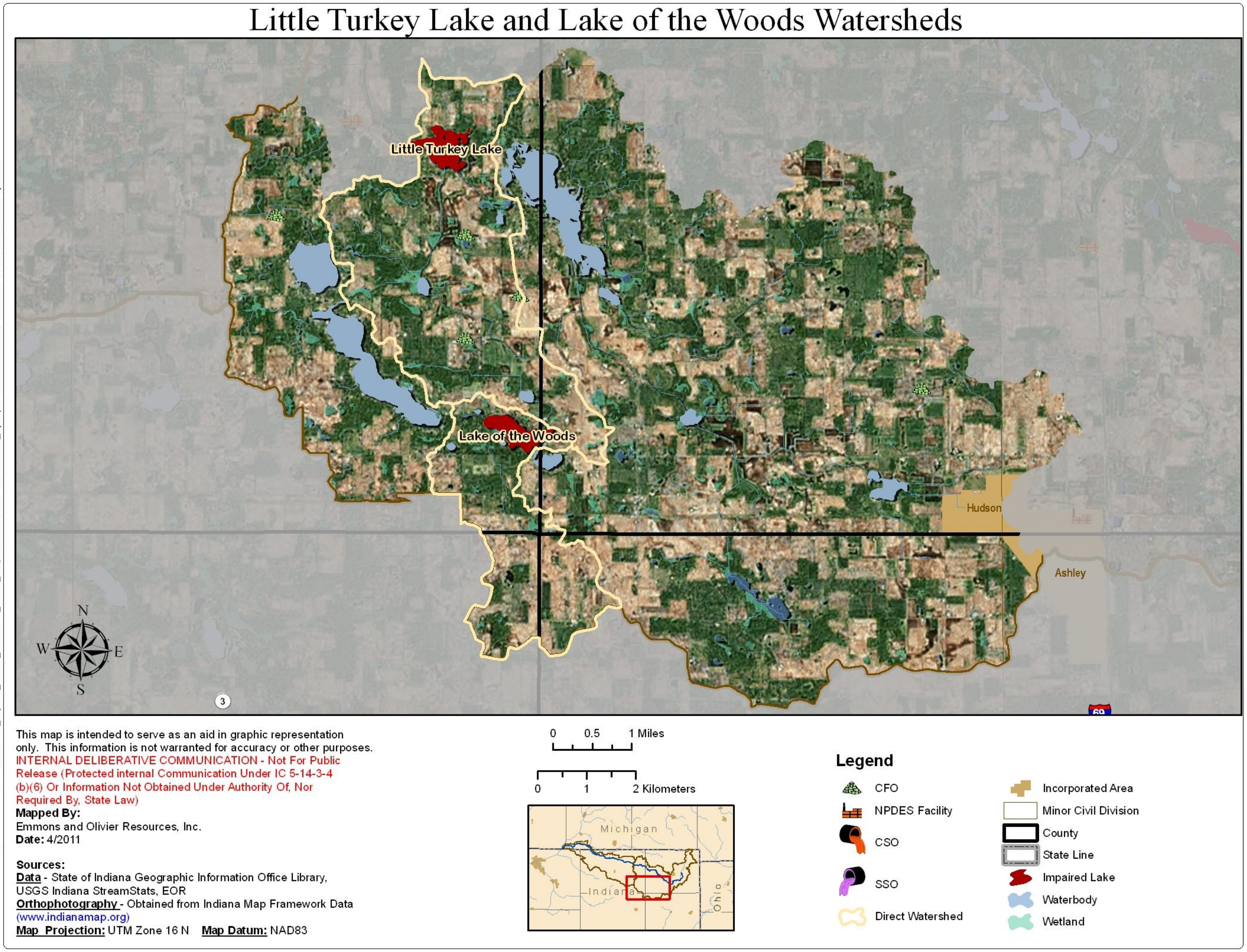

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Figure 20. Little Turkey Lake and Lake of the Woods Watersheds

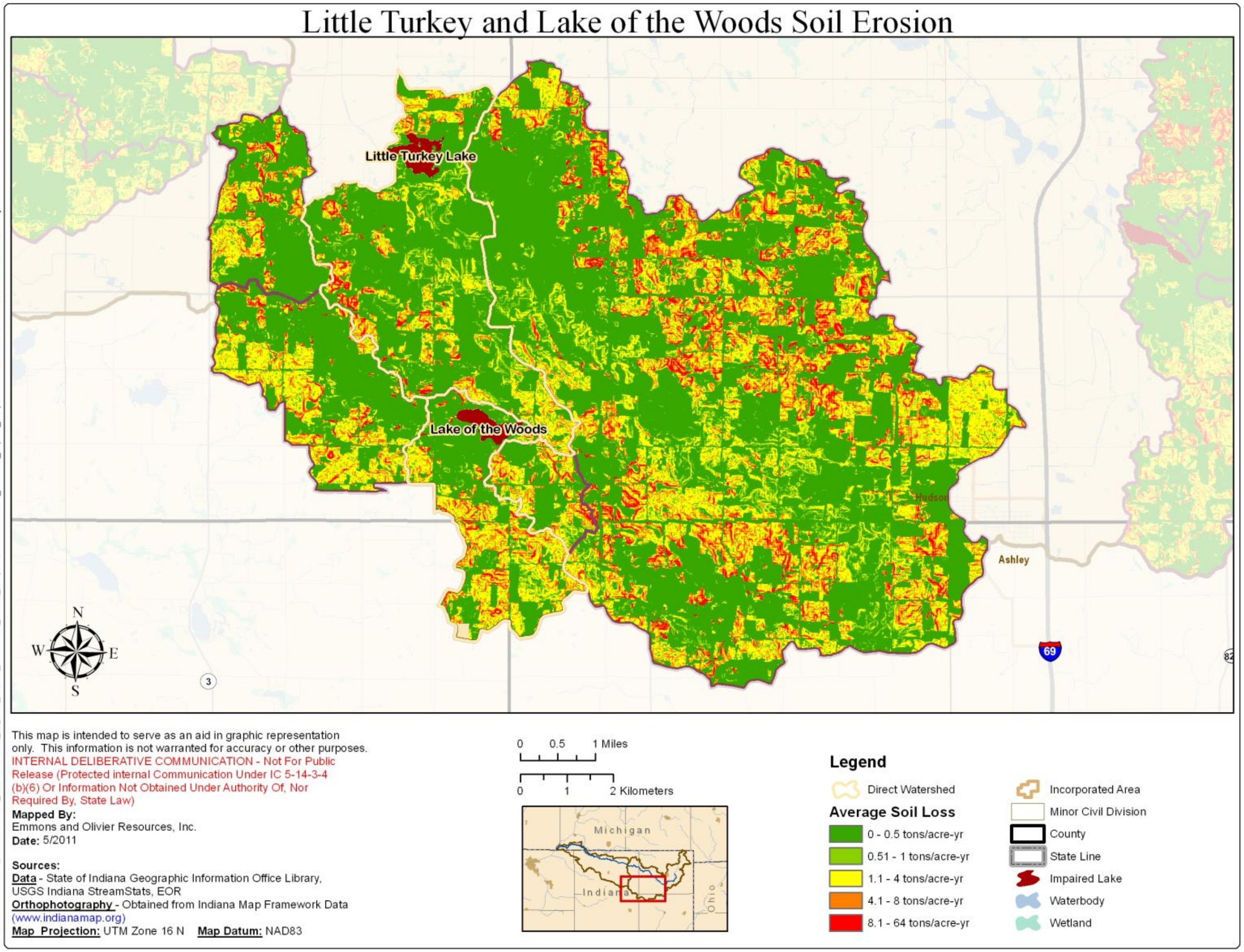

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Figure 21. Soil erosion characteristics in Little Turkey Lake and Lake of the Woods Watersheds

Land Cover

At present, the dominant land cover in the Lake of the Woods watershed is cultivated crops (Table 43).

Table 43. Lake of the Woods Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage		Entire Drainage (including McClish Lake watershed and lake)	
	Acres	% of Watershed	Acres	% of Watershed
Barren Land	-	-	-	-
Cultivated Crops	1302	54%	1779	55%
Deciduous Forest	153	6.3%	206	6.4%
Developed, Low Intensity	53	2.2%	82	2.5%
Developed, Medium Intensity	2.0	0.081%	2.0	0.061%
Developed, High Intensity	-	-	-	-
Developed, Open Space	81	3.3%	99	3.1%
Emergent Herbaceous Wetlands	-	-	1.8	0.055%
Evergreen Forest	17	0.71%	19	0.59%
Hay/Pasture	354	15%	463	14%
Herbaceous	37	1.6%	56	1.7%
Mixed Forest	3.9	0.16%	3.9	0.12%
Open Water	37	1.5%	76	2.3%
Shrub/Scrub	28	1.2%	35	1.08%
Woody Wetlands	354	15%	417	13%
Total*	**2422**	**100%**	**3241**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding

Water Quality

Phosphorus monitoring data are available from 1989, 1992-2002, 2004-2006, 2008-2010. The lake does not meet lake water quality standards for TP (Table 44). Table 30 shows additional detail regarding the phosphorus monitoring data available for Lake of the Woods.

Table 44. Lake of the Woods surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.036	0.030
Chlor-a (µg/L)	3.9	none
Secchi transparency (m)	2.1	none

Existing Phosphorus Loading

Watershed Phosphorus Loading

The contributing watershed to Lake of the Woods includes watershed runoff coming from the direct drainage to the lake and drainage from McClish Lake. It is estimated that Lake of the Woods receives 3213 pounds of phosphorus annually from external sources (Table 45). Approximately 2% of the phosphorus is coming from McClish Lake.

Table 45. Lake of the Woods external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	3146	98%
Upstream Lake Loading (McClish Lake)	67	2.1%
Total*	**3213**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Internal Phosphorus Loading

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in Lake of the Woods is higher than the average of the field datasets used for development of the BATHTUB model.

Lake of the Woods monitoring data indicate that internal loading is a source of phosphorus to the lake. Dissolved oxygen concentrations were consistently below 1 mg/l at a depth of 17 meters and below. At these low dissolved oxygen concentrations, phosphorus is released from the sediment to the hypolimnion and mixes with the surface water when the water column mixes during fall turnover. Lake of the Woods's monitoring data during thermal stratification is evidence of this process occurring; during four of the five days that the deep hole was monitored, hypolimnetic (bottom water) soluble and total phosphorus concentrations were higher than epilimnetic (surface water) concentrations (Table 46). This phosphorus is then available for algal uptake and growth during the following growing season.

Internal loading in the hypolimnion is not as evident at the other monitoring locations (Table 46).

Table 46. Lake of the Woods water quality data from Clean Lakes Program Data Summary

Date	Site (max depth, m)	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
		Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
7/19/1989	deep hole (24.7)	0.01	0.33	0.03	0.33
8/25/1992	deep hole (24.7)	0.01	0.01	0.03	0.02
8/26/1997	deep hole (24.7)	0.01	0.24	0.02	0.29
8/5/2002	deep hole (24.7)	0.01	0.20	0.02	0.22
7/24/2006	site 1 (25.3)**	0.01	0.11	0.05	0.17
7/24/2006	site 2 (22.3)	0.01	0.02	0.05	0.04
7/24/2006	site 3 (10.6)	0.01	0.01	0.05	0.05

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l
**It is assumed that site 1 is the site at the deep hole

In the 2006 Clean Lakes Program monitoring, blue-green algal dominance was high (79-94%), and the zooplankton community was skewed towards smaller zooplankton (rotifers, as opposed to cladocera) that have less ability to control algal densities.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Lake of the Woods is 2245 lb/yr, to be split among allocations according to Table 47. To meet the TMDL, the total load to the lake needs to be reduced by 968 lb/yr, or 30%. There are no NPDES-permitted sources of phosphorus in the Lake of the Woods watershed.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 47. Lake of the Woods allocation summary

Allocation*	lb/yr	lb/day
TMDL	2245	6.2
MOS	225	0.62
WLA	0.0	0.0
LA	2020	5.5

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Implementation Strategy

Lake of the Woods is in the Little Turkey Lake – Turkey Creek HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the Lake of the Woods watershed. The majority of the land use in the watershed is agricultural in nature. The pollutant sources and management practices for the Little Turkey Lake – Turkey Creek HUC 12 watershed (**Error! Reference source not found.**) apply to the Lake of the Woods watershed, in addition to the other sources and implementation approaches identified in Table 48. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 48. Implementation approaches to addresses sources in Lake of the Woods watershed

Type	Source Summary	Implementation Section
Soil Erosion	Highly erodible soils are located in the southern half of the Lake of the Woods drainage area (see Figure 21 on page 43)	**Error! Reference source not found.**
Internal Loading	Phosphorus release due to anoxic hypolimnion	B.1.1
Internal Loading	Potential imbalanced in-lake ecological interactions	B.1.1
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**

Potential Priority Implementation Areas

- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the land application of manure and other fertilizers.
- Potential field erosion in the drainage area south of Lake of the Woods.

Little Turkey Lake

Physical Characteristics

Little Turkey Lake (Table 49) is located in LaGrange County (see Figure 20). Several lakes discharge to Little Turkey Lake: Pretty Lake, Big Long Lake, Lake of the Woods (which is also impaired), and Big Turkey Lake. Patches of highly erodible soils exist throughout the Little Turkey Lake drainage area although they appear to be somewhat isolated (see Figure 21).

Table 49. Little Turkey Lake characteristics

Characteristic	Value	Source
Lake total surface area (ac)	133	USGS National Hydrography Dataset
Lake volume (ac-ft)	1,317	Calculated (surface area x mean depth)
Mean depth (ft)	9.9	Calculated based on IN-DNR bathymetry data collected on July 31, 2007
Maximum depth (ft)	34	Calculated based on IN-DNR bathymetry data collected on July 31, 2007
Drainage area (acres)	35,942	USGS Indiana StreamStats application & EOR
Watershed area: lake area	270	Calculated (watershed area / lake area)
Upstream Lakes*	Pretty, Big Long, Lake of the Woods, Big Turkey	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported 'Drainage area' in this table.

Land Cover

At present, the dominant land cover in the Little Turkey Lake watershed is cultivated crops (Table 50).

Table 50. Little Turkey Lake Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage		Entire Drainage (including Pretty, Big Long, Lake of the Woods, and Big Turkey Lake watersheds and their lakes)	
	Acres	% of Watershed	Acres	% of Watershed
Barren Land	-	-	-	-
Cultivated Crops	2125	44%	17516	49%
Deciduous Forest	361	7.4%	2037	5.7%
Developed, Low Intensity	93	1.9%	933	2.6%
Developed, Medium Intensity	14	0.28%	102	0.28%
Developed, High Intensity	4.1	0.08%	19	0.05%
Developed, Open Space	194	4.0%	1597	4.4%
Emergent Herbaceous Wetlands	4.3	0.089%	56	0.16%
Evergreen Forest	3.7	0.077%	127	0.35%
Hay/Pasture	1032	21%	6228	17%
Herbaceous	75	1.5%	685	2.0%
Mixed Forest	0.082	0.00%	7.9	0.022%
Open Water	69	1.4%	1507	4.2%
Shrub/Scrub	-	-	424	1.2%
Woody Wetlands	905	19%	4702	13%
Total*	**4880**	**100%**	**35942**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Water Quality

Phosphorus monitoring data are available from 1989, 1992-2008, 2010. The lake does not meet lake water quality standards for TP (Table 51). Table 30 shows additional detail regarding the phosphorus monitoring data available for Little Turkey Lake.

Table 51. Little Turkey Lake surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.042	0.030
Chlor-*a* (µg/L)	6.7	none
Secchi transparency (m)	1.5	none

Existing Phosphorus Loading

Watershed Phosphorus Loading

The contributing watershed to Little Turkey Lake includes watershed runoff coming from the direct drainage to the lake and drainage from Pretty, Big Long, Lake of the Woods, and Big Turkey Lakes. It is estimated that Little Turkey Lake receives 8,684 pounds of phosphorus annually from external sources (Table 52). Approximately 33% of the phosphorus is coming from upstream lakes.

Table 52. Little Turkey Lake external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	5807	67%
Upstream Lake Loading (Pretty, Big Long, Lake of the Woods, and Big Turkey)	2877	33%
Total*	**8684**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Internal Phosphorus Loading

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in Little Turkey Lake is higher than the average of the field datasets used for development of the BATHTUB model.

Little Turkey Lake monitoring data indicate that internal loading is a source of phosphorus to the lake. Dissolved oxygen concentrations were consistently below 1 mg/l at a depth of 5 meters and below. At these low dissolved oxygen concentrations, phosphorus is released from the sediment to the hypolimnion and mixes with the surface water when the water column mixes during fall turnover. Lake of the Woods's monitoring data during thermal stratification is evidence of this process occurring; during four of the five days that the deep hole was monitored, hypolimnetic (bottom water) soluble and total phosphorus concentrations were higher than epilimnetic (surface water) concentrations (Table 53). On the remaining day (8/6/2002), soluble phosphorus was higher in the hypolimnion whereas total phosphorus was not. However, since Little Turkey Lake has a very short residence time (less than one month), the phosphorus will have flushed downstream by the time that the next growing season has begun. The phosphorus will be available for algal growth in downstream waterbodies.

Internal loading in the hypolimnion is not as evident at the other monitoring locations (Table 53).

Table 53. Little Turkey Lake water quality data from Clean Lakes Program Data Summary

Date	Site (max depth, m)	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
		Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
7/24/1989	deep hole (8.5)	0.01	0.04	0.03	0.09
7/27/1993	deep hole (8.5)	0.01	0.53	0.02	0.62
8/25/1997	deep hole (10.1)	0.01	0.56	0.08	0.58
8/6/2002	deep hole (10.1)	0.01	0.29	0.03	0.01
7/24/2006	1 (10.3)**	0.01	0.10	0.05	0.14
7/24/2006	2 (3.3)	0.01	0.01	0.03	0.05
7/24/2006	3 (3)	0.01	0.01	0.04	0.06

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l
**It is assumed that site 1 is the site at the deep hole

In the 2006 Clean Lakes Program monitoring, blue-green algal dominance was high (63-88%), and the zooplankton community was skewed towards smaller zooplankton (rotifers, as opposed to cladocera) that have less ability to control algal densities.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Little Turkey Lake is 5236 lb/yr, to be split among allocations according to Table 54. To meet the TMDL, the total load to the lake needs to be reduced by 3448 lb/yr, or 40%. There are no NPDES-permitted sources of phosphorus in the watershed. There are five CFOs (#291, 659, 1005, 6390, and 6650) in the watershed; CFOs are zero discharge facilities and receive a LA of zero.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 54. Little Turkey Lake allocation summary

Allocation*	lb/yr	lb/day
TMDL	5236	14
MOS	524	1.4
WLA	0.0	0.0
LA	4712	13

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Implementation Strategy

Little Turkey Lake is in the Little Turkey Lake – Turkey Creek HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the Little Turkey Lake watershed. The majority of the land use in the watershed is agricultural in nature. The pollutant sources and management practices for the Little Turkey Lake – Turkey Creek HUC 12 watershed (**Error! Reference source not found.**) apply to the Little Turkey Lake watershed, in addition to the other sources and implementation approaches identified in Table 55. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 55. Implementation approaches to addresses sources in Little Turkey Lake watershed

Type	Source Summary	Implementation Section
Soil Erosion	Patches of highly erodible soils exist throughout the Little Turkey Lake drainage area although they appear to be somewhat isolated (see Figure 21 on page 43)	**Error! Reference source not found.**
Internal Loading	Phosphorus release due to anoxic hypolimnion	B.1.1
Internal Loading	Potential imbalanced in-lake ecological interactions	B.1.1
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**

<u>Potential Priority Implementation Areas</u>

- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the land application of manure and other fertilizers.
- Potential field erosion in the drainage area south of Little Turkey Lake.

Long Lake

Physical Characteristics

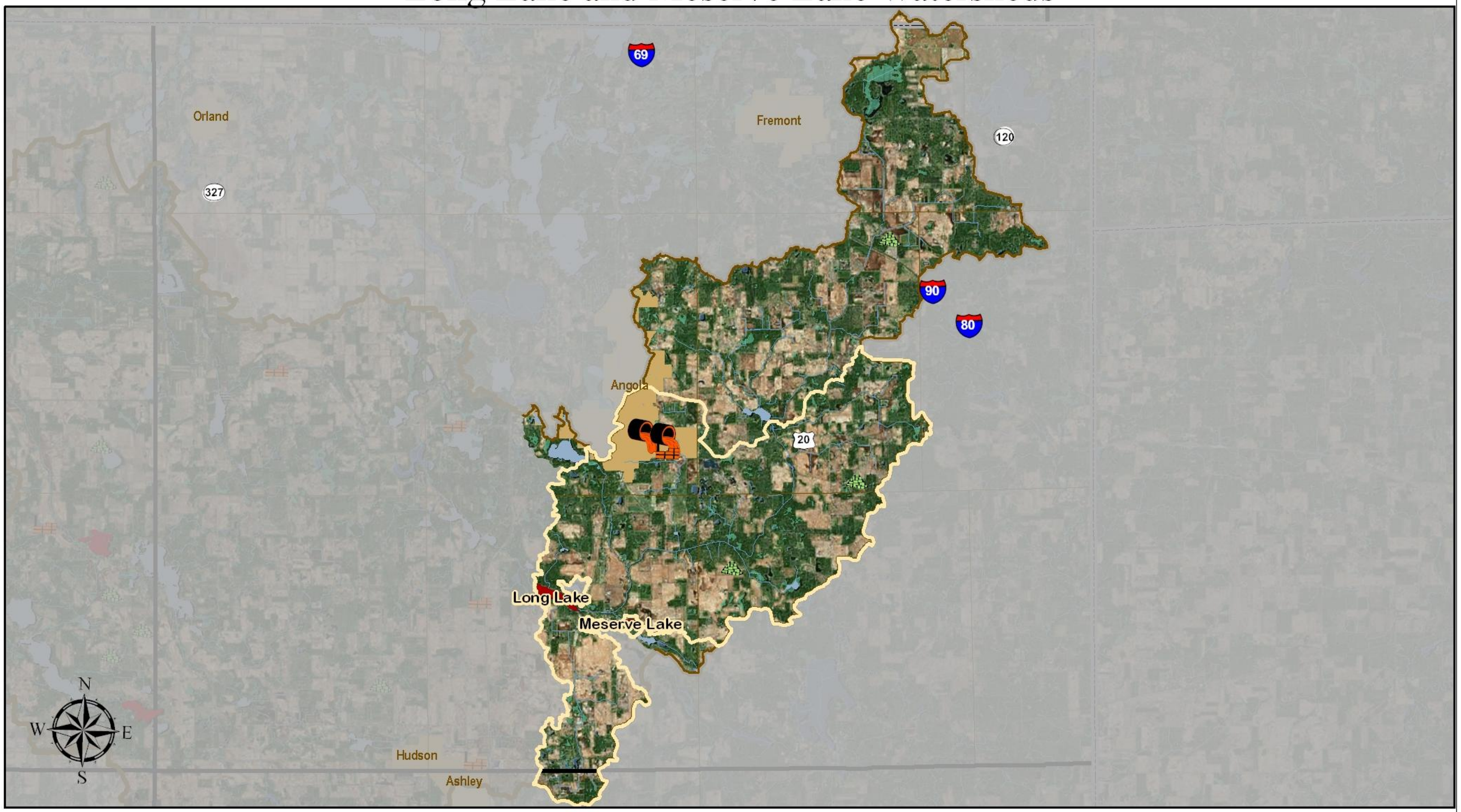
Long Lake (Table 56) is located in Steuben County (Figure 22). Several lakes discharge to Long Lake: Meserve Lake (which is also impaired), Fox Lake, and Pigeon Lake. Upstream of Long Lake are the following landlocked lakes: Gravel Pit and Pleasant. The Long Lake drainage area contains a large amount of highly erodible soils throughout its drainage area (Figure 23).

Table 56. Long Lake characteristics

Characteristic	Value	Source
Lake total surface area (ac)	92	USGS National Hydrography Dataset
Lake volume (ac-ft)	1,564	Calculated (surface area x mean depth)
Mean depth (ft)	17	Calculated based on Indiana DNR August 1958 hydrographic survey prepared cooperatively by the USGS
Maximum depth (ft)	32	Indiana DNR August 1958 hydrographic survey prepared cooperatively by the USGS
Drainage area (acres)	44,651	USGS Indiana StreamStats application & EOR
Watershed area: lake area	485	Calculated (watershed area / lake area)
Upstream Lakes*	Meserve, Fox, Pigeon	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported ‘Drainage area’ in this table.

Long Lake and Meserve Lake Watersheds



This map is intended to serve as an aid in graphic representation only. This information is not warranted for accuracy or other purposes.
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Mapped By:
Emmons and Olivier Resources, Inc.
Date: 4/2011

Sources:
Data - State of Indiana Geographic Information Office Library, USGS Indiana StreamStats, EOR
Orthophotography - Obtained from Indiana Map Framework Data (www.indianamap.org)
Map Projection: UTM Zone 16 N **Map Datum:** NAD83

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0 5 Kilometers

Legend
- CFO
- NPDES Facility
- CSO
- SSO
- Direct Watershed
- Incorporated Area
- Minor Civil Division
- County
- State Line
- Impaired Lake
- Waterbody
- Wetland

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Figure 22. Long and Meserve Lake Watersheds

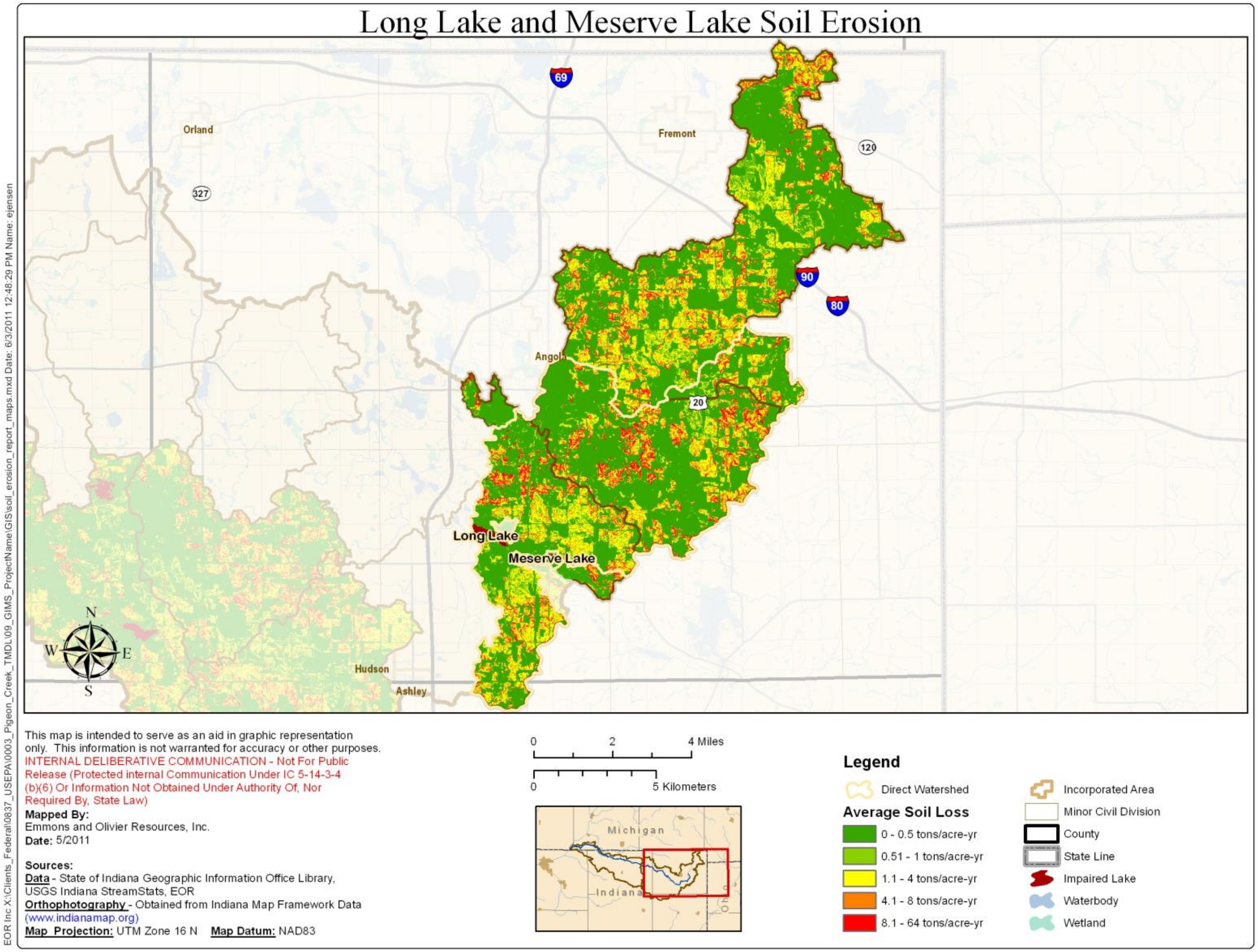

Figure 23. Soil erosion characteristics in Long and Meserve Lake Watersheds and the Mud Creek-Pigeon Creek HUC 12 Watershed

Land Cover

At present, the dominant land covers in the Long Lake watershed are cultivated crops and hay/pasture (Table 57).

Table 57. Long Lake Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage		Entire Drainage (including Meserve, Fox, and Pigeon Lake watersheds and their lakes)	
	Acres	% of Watershed	Acres	% of Watershed
Barren Land	-	-	2.4	0.0053%
Cultivated Crops	10284	44%	19647	44%
Deciduous Forest	982	4.2%	1839	4.1%
Developed, Low Intensity	860	3.7%	1248	2.8%
Developed, Medium Intensity	239	1.0%	341	0.76%
Developed, High Intensity	105	0.44%	120	0.27%
Developed, Open Space	1276	5.4%	2604	5.8%
Emergent Herbaceous Wetlands	43	0.18%	89	0.20%
Evergreen Forest	23	0.10%	71	0.16%
Hay/Pasture	5210	22%	10091	23%
Herbaceous	349	1.5%	842	1.9%
Mixed Forest	9.0	0.038%	42	0.095%
Open Water	219	0.93%	574	1.3%
Shrub/Scrub	2.8	0.012%	3.9	0.0088%
Woody Wetlands	3952	17%	7136	16%
Total*	**23553**	**100%**	**44651**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Water Quality

Phosphorus monitoring data are available from 1989, 1990, 1992-1999, 2002, 2009, 2010. The lake does not meet lake water quality standards for TP (Table 58). Table 30 shows additional detail regarding the phosphorus monitoring data available for Long Lake.

Table 58. Long Lake surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.056	0.030
Chlor-*a* (µg/L)	19	none
Secchi transparency (m)	1.1	none

Existing Phosphorus Loading

<u>Watershed Phosphorus Loading</u>

The contributing watershed to Long Lake includes watershed runoff coming from the direct drainage to the lake and drainage from Meserve, Fox, and Pigeon Lakes. It is estimated that Long Lake receives 26,432 pounds of phosphorus annually from external sources (Table 59). Approximately 11% of the phosphorus is coming from upstream lakes. Approximately 11% is coming from Angola Municipal wastewater treatment plant.

Table 59. Long Lake external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	20,617	78%
Upstream Lake Loading (Meserve, Fox, and Pigeon Lakes)	2,996	11%
Angola Municipal WWTP (Permit # IN0021296)	2,786	11%
Angola Municipal WWTP CSOs (Pipe ID 002 and 003, Permit # IN0021296)	33	0.12%
Total*	**26,432**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Internal Phosphorus Loading

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in Long Lake is higher than the average of the field datasets used for development of the BATHTUB model.

Long Lake monitoring data indicate that internal loading is a source of phosphorus to the lake. Dissolved oxygen concentrations were consistently below 1 mg/l at a depth of 5 meters and below. At these low dissolved oxygen concentrations, phosphorus is released from the sediment to the hypolimnion and mixes with the surface water when the water column mixes during fall turnover. Long Lake's monitoring data during thermal stratification is evidence of this process occurring; during all of the days that the lake was monitored, hypolimnetic (bottom water) total phosphorus concentrations were higher than (at least double) epilimnetic (surface water) concentrations (Table 60). The same was true for soluble phosphorus during four of the five monitoring days. However, since Long Lake has a relatively short residence time (less than one month), the phosphorus will have flushed downstream by the time that the next growing season has begun. The phosphorus will be available for algal growth in downstream waterbodies.

Table 60. Long Lake water quality data from Clean Lakes Program Data Summary

Date	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
	Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
7/18/1989	0.01	0.36	0.06	0.37
8/13/1990	0.01	0.27	0.05	0.32
8/17/1992	0.01	0.01	0.06	0.65
8/4/1997	0.01	0.73	0.07	0.78
7/8/2002	0.01	0.03	0.04	0.08
7/6/2009	0.01	0.11	0.02	0.17

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l

In the 2009 Clean Lakes Program monitoring, blue-green algal dominance was high (96%), indicating eutrophic conditions.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Long Lake is 8,700 lb/yr, to be split among allocations according to Table 61. To meet the TMDL, the total load to the lake needs to be reduced by 17,732 lb/yr, or 67%. The NPDES-permitted sources in the Long Lake watershed receive individual WLAs (Table 62). There are three CFOs (#1082, 1108, 6067) in the watershed; CFOs are zero discharge facilities and receive a LA of zero.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 61. Long Lake allocation summary

Allocation*	lb/yr	lb/day
TMDL	8,700	24
MOS	870	2.4
WLA	5,864	16
LA	1,966	5.4

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Table 62. Long Lake WLAs

Source	Permit #	WLA	
		lb/yr	lb/day
Angola Municipal WWTP	IN0021296	5110	14
Angola Municipal WWTP CSO (Pipe ID 002)	IN0021296	402	1.1
Angola Municipal WWTP CSO (Pipe ID 003)	IN0021296	19	0.053
City of Angola and Trine University MS4	INR040005	333	0.91

Implementation Strategy

Long Lake is in the Long Lake – Pigeon Creek HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the Long Lake watershed. The majority of the land use in the watershed is agricultural in nature. The pollutant sources and management practices for the Long Lake – Pigeon Creek HUC 12 watershed (**Error! Reference source not found.**) apply to the Long Lake watershed, in addition to the other sources and implementation approaches identified in Table 63. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 63. Implementation approaches to addresses sources in Long Lake watershed

Type	Source Summary	Implementation Section
Soil Erosion	The Long Lake drainage area contains a large amount of highly erodible soils throughout its drainage area (see Figure 23 on page 53)	**Error! Reference source not found.**
Internal Loading	Phosphorus release due to anoxic hypolimnion	B.1.1
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**

Potential Priority Implementation Areas

- City of Angola WWTP: Implementation should address the permit related activities for the WWTP (described in Section **Error! Reference source not found.**). Implementation for the CSOs that are related to the WWTP should focus on minimizing overflow events (described in Section **Error! Reference source not found.**).

- City of Angola MS4: As a phase II community, Angola has an NPDES permit that requires six minimum control measures (MCMs). A description of the MCMs and guidance on the types of activities to comply with the MCMs is provided in Section **Error! Reference source not found.**.
- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the land application of manure and other fertilizers.
- Potential field erosion in the drainage area.

Meserve Lake

Physical Characteristics

Meserve Lake (Table 64) is located in Steuben County (see Figure 22). Gooseneck Lake discharges to Meserve Lake. The Meserve Lake drainage area contains no highly erodible soils (see Figure 23).

Table 64. Meserve Lake characteristics

Characteristic	Value	Source
Lake total surface area (ac)	18	USGS National Hydrography Dataset
Lake volume (ac-ft)	198	Calculated (surface area x mean depth)
Mean depth (ft)	11	Calculated based on IN-DNR bathymetry data collected on July 8, 2009
Maximum depth (ft)	24	Calculated based on IN-DNR bathymetry data collected on July 8, 2009
Drainage area (acres)	620	USGS Indiana StreamStats application & EOR
Watershed area: lake area	34	Calculated (watershed area / lake area)
Upstream Lakes*	Gooseneck	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported 'Drainage area' in this table.

Land Cover

At present, the dominant land covers in the Meserve Lake watershed are cultivated crops and hay/pasture (Table 65).

Table 65. Meserve Lake Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage		Entire Drainage (including Gooseneck Lake watershed and lake)	
	Acres	% of Watershed	Acres	% of Watershed
Barren Land	-	-	-	-
Cultivated Crops	14	17%	219	35%
Deciduous Forest	-	-	24	3.8%
Developed, Low Intensity	14	19%	18	3.0%
Developed, Medium Intensity	-	-	-	-
Developed, High Intensity	-	-	-	-
Developed, Open Space	8.6	11%	40	6.4%
Emergent Herbaceous Wetlands	1.2	1.5%	1.2	0.19%
Evergreen Forest	-	-	3.7	0.60%
Hay/Pasture	15	19%	177	29%
Herbaceous	0.69	0.88%	29	4.7%
Mixed Forest	-	-	-	-
Open Water	1.6	2.1%	30	4.8%
Shrub/Scrub	-	-	-	-
Woody Wetlands	23	30%	78	13%
Total*	**78**	**100**	**620**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Water Quality

Phosphorus monitoring data are available from 1990 and 1992. Chlorophyll-*a* data were not available for Meserve Lake. The lake does not meet lake water quality standards for TP (Table 66). Table 30 shows additional detail regarding the phosphorus monitoring data available for Meserve Lake.

Table 66. Meserve Lake surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.034	0.030
Chlor-*a* (µg/L)	n/a	none
Secchi transparency (m)	3.6	none

Existing Phosphorus Loading

Watershed Phosphorus Loading

The contributing watershed to Meserve Lake includes watershed runoff coming from the direct drainage to the lake and drainage from Gooseneck Lake. It is estimated that Meserve Lake receives 82 pounds of phosphorus annually from external sources (Table 67). Approximately 36% of the phosphorus is coming from Gooseneck Lake.

Table 67. Meserve Lake external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	52	64%
Upstream Lake Loading (Gooseneck Lake)	30	36%
Total*	**82**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

<u>Internal Phosphorus Loading</u>

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in Meserve Lake is higher than the average of the field datasets used for development of the BATHTUB model.

Meserve Lake monitoring data indicate that internal loading might be a source of phosphorus to the lake. During one of the monitoring days (7/10/1990), hypolimnetic (bottom water) total phosphorus concentrations were higher than epilimnetic (surface water) concentrations (Table 68). However, hypolimnetic soluble phosphorus concentrations were the same as epilimnetic concentrations. The bottom waters remained oxic, so it is not clear why the total phosphorus concentration was so high in the hypolimnion. On the other monitoring day (8/18/1992), hypolimnetic soluble and total phosphorus concentrations were not higher than epilimnetic concentrations.

Table 68. Meserve Lake water quality data from Clean Lakes Program Data Summary

Date	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
	Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
7/10/1990	0.01	0.01	0.01	0.36
8/18/1992	0.01	0.01	0.06	0.04

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l

Clean Lakes Program data summaries indicate that the zooplankton community was skewed towards smaller zooplankton (rotifers, as opposed to cladocera) that have less ability to control algal densities.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Meserve Lake is 75 lb/yr, to be split among allocations according to Table 69. To meet the TMDL, the total load to the lake needs to be reduced by 7 lb/yr, or 8.5%. There are no NPDES-permitted sources in the Meserve Lake watershed; therefore, there are no individual WLAs.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 69. Meserve Lake allocation summary

Allocation*	lb/yr	lb/day
TMDL	75	0.21
MOS	7.5	0.021
WLA	0.0	0.0
LA	68	0.19

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Implementation Strategy

Meserve Lake is in the Long Lake – Pigeon Creek HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the Meserve Lake watershed. The majority of the land use in the watershed is agricultural in nature. The pollutant sources and management practices for the Long Lake – Pigeon Creek HUC 12 watershed (**Error! Reference source not found.**) apply to the Meserve Lake watershed, in addition to the other sources and implementation approaches identified in Table 70. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 70. Implementation approaches to addresses sources in Meserve Lake watershed

Type	Source Summary	Implementation Section
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**
Internal Loading	Potential imbalanced in-lake ecological interactions	B.1.1
Internal Loading	Control of curly-leaf pondweed	B.1.1

Starting in approximately 2006, the aquatic plant parrot feather (*Myriophyllum aquaticum*) was found in Meserve Lake. Parrot feather is a type of milfoil that is native to South America, and it often becomes invasive in waters such as small lakes and drainage ditches outside of its native range. It is used in aquaria and was likely introduced into the lake by an owner of an aquarium or garden pond. If not controlled, the plant has the potential to spread throughout the lake and other waterbodies, impairing recreational and ecological functions.

An aquatic plant management plan is detailed in the Meserve Lake Aquatic Vegetation Management Plan Update (Aquatic Enhancement & Survey, Inc. 2009). Areas of the lake containing parrot feather plant were treated in 2008, and management activities for 2009 and beyond were detailed in the plan with the goal of 1) achieving eradication of parrot feather in Meserve Lake by the end of the 2009 season, and 2) increasing awareness among lake residents and users that parrot feather is invasive and that measures should be taken to prevent the re-introduction and spread of the plant in the lake. For 2010, planned activities included hand removal of free floating plants and herbicide application.

Curly-leaf pondweed was also found in low abundance in Meserve Lake. Its presence in the lake is minimal and it was determined in the Aquatic Vegetation Management Plan Update that it does not warrant treatment, but that it should be monitored.

<u>Potential Priority Implementation Areas</u>

- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the land application of manure and other fertilizers.

North Twin Lake

Physical Characteristics

North Twin Lake (Table 71) is located in LaGrange County (Figure 24). Still Lake discharges to North Twin Lake. The North Twin Lake drainage area contains only small portions of highly erodible soils, just to the east of the lake (Figure 25).

Table 71. North Twin Lake characteristics

Characteristic	Value	Source
Lake total surface area (ac)	136	USGS National Hydrography Dataset
Lake volume (ac-ft)	2,176	Calculated (surface area x mean depth)
Mean depth (ft)	16	Calculated based on Indiana DNR August 1958 hydrographic survey prepared cooperatively by the USGS
Maximum depth (ft)	40	Indiana DNR August 1958 hydrographic survey prepared cooperatively by the USGS
Drainage area (acres)	1,011	USGS Indiana StreamStats application & EOR
Watershed area: lake area	7.4	Calculated (watershed area / lake area)
Upstream Lakes*	Still	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported ‘Drainage area’ in this table.

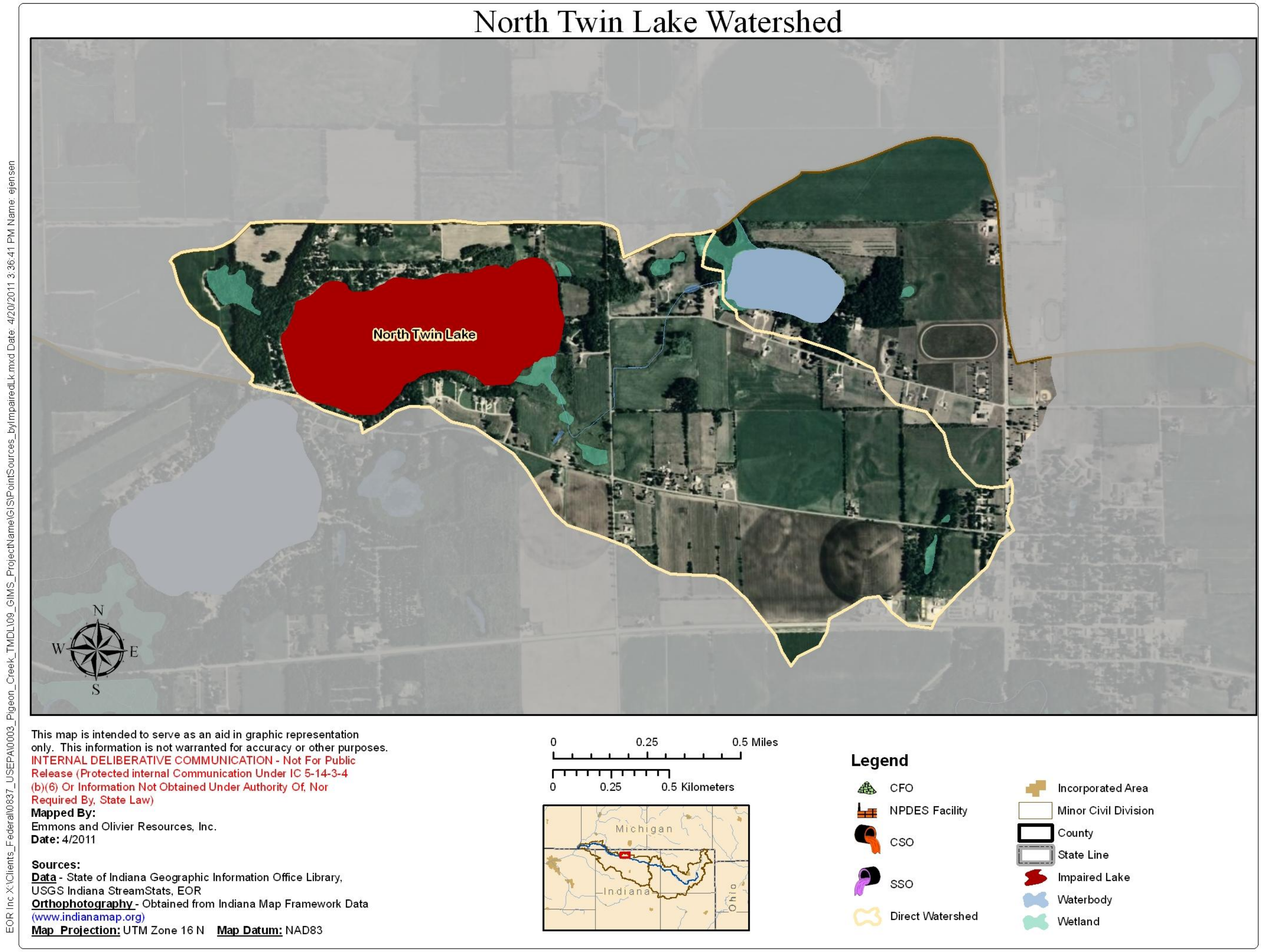

Figure 24. North Twin Lake Watershed

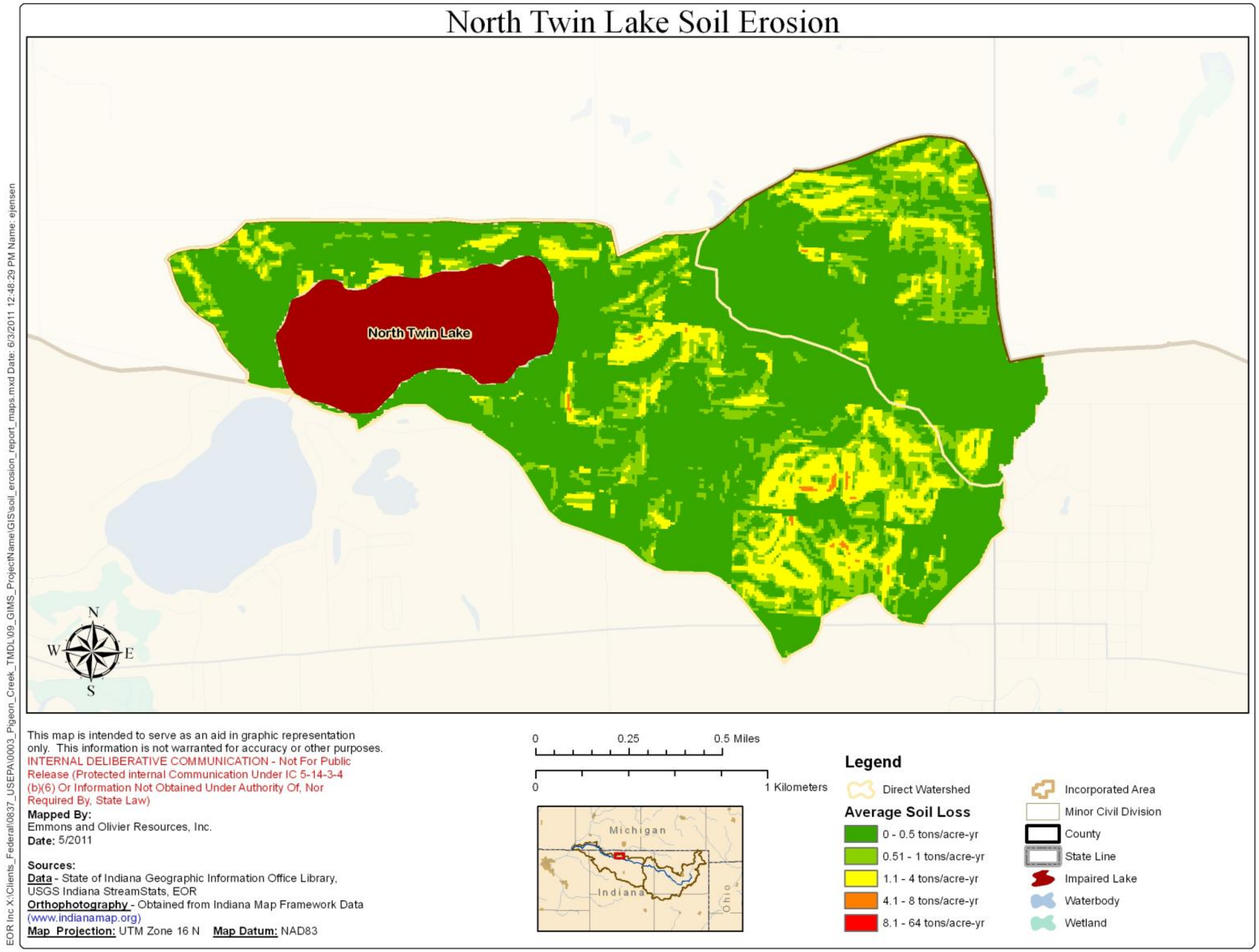

Figure 25. Soil erosion characteristics in North Twin Lake Watershed

Land Cover

At present, the dominant land cover in the North Twin Lake watershed is cultivated crops (Table 72).

Table 72. North Twin Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage		Entire Drainage (including Still Lake watershed and lake)	
	Acres	% of Watershed	Acres	% of Watershed
Barren Land	-	-	-	-
Cultivated Crops	412	58%	552	55%
Deciduous Forest	13	1.8%	17	1.7%
Developed, Low Intensity	51	7.2%	64	6.3%
Developed, Medium Intensity	0.40	0.057%	3.3	0.33%
Developed, High Intensity	1.3	0.19%	1.3	0.13%
Developed, Open Space	28	3.9%	46	4.5%
Emergent Herbaceous Wetlands	-	-	-	-
Evergreen Forest	-	-	-	-
Hay/Pasture	94	13%	150	15%
Herbaceous	3.1	0.44%	16	1.6%
Mixed Forest	1.3	0.19%	1.3	0.13%
Open Water	7.3	1.0%	38	3.7%
Shrub/Scrub	-	-	-	-
Woody Wetlands	97	14%	122	12%
Total*	**709**	**100%**	**1011**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Water Quality

Phosphorus monitoring data are available from 1989, 1993, and 2000. The lake does not meet lake water quality standards for TP (Table 73). Table 30 shows additional detail regarding the phosphorus monitoring data available for North Twin Lake.

Table 73. North Twin Lake surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.040	0.030
Chlor-*a* (µg/L)	0.65	none
Secchi transparency (m)	2.0	none

Existing Phosphorus Loading

Watershed Phosphorus Loading

The contributing watershed to North Twin Lake includes watershed runoff coming from the direct drainage to the lake and drainage from Still Lake. It is estimated that North Twin Lake receives 82 pounds of phosphorus annually from external sources (Table 74). Approximately 10% of the phosphorus is coming from Still Lake.

Table 74. North Twin Lake external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	792	90%
Upstream Lake Loading (Still Lake)	90	10%
Total*	**882**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Internal Phosphorus Loading

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in North Twin Lake is higher than the average of the field datasets used for development of the BATHTUB model.

North Twin Lake monitoring data indicate that internal loading due to anoxia in bottom waters is likely not a source of phosphorus to the lake. There was no difference in the hypolimnetic (bottom water) soluble and total phosphorus concentrations and epilimnetic (surface water) concentrations (Table 75).

Table 75. North Twin Lake water quality data from Clean Lakes Program Data Summary

Date	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
	Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
7/31/1989	0.01	0.01	0.09	0.08
7/20/1993	0.01	0.01	0.01	0.01
7/6/2000	0.01	0.01	0.03	0.03

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l

Clean Lakes Program data summaries indicate that the zooplankton community was skewed towards smaller zooplankton (rotifers, as opposed to cladocera) that have less ability to control algal densities.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of North Twin Lake is 565 lb/yr, to be split among allocations according to Table 76. To meet the TMDL, the total load to the lake needs to be reduced by 317 lb/yr, or 36%. There are no NPDES-permitted sources in the North Twin Lake watershed; therefore, there are no individual WLAs.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 76. North Twin Lake allocation summary

Allocation*	lb/yr	lb/day
TMDL	565	1.5
MOS	57	0.16
WLA	0.0	0.0
LA	508	1.4

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Implementation Strategy

North Twin Lake is in the VanNatta Ditch – Pigeon River HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the North Twin Lake watershed. The majority of the land use in the watershed is agricultural in nature. The pollutant sources and management practices for the VanNatta Ditch – Pigeon River HUC 12 watershed (**Error! Reference source not found.**) apply to the North Twin Lake watershed, in addition to the other sources and implementation approaches identified in Table 77. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 77. Implementation approaches to addresses sources in North Twin Lake watershed

Type	Source Summary	Implementation Section
Soil Erosion	The North Twin Lake drainage area contains only small portions of highly erodible soils, just to the east of the lake (see Figure 25 on page 63)	**Error! Reference source not found.**
Internal Loading	Potential imbalanced in-lake ecological interactions	B.1.1
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**

Potential Priority Implementation Areas

- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the land application of manure and other fertilizers.

Royer Lake

Physical Characteristics

Royer Lake (Table 78) is located in LaGrange County (see Figure 18). There are no upstream lakes in the Royer Lake watershed. Highly erodible soils with the occasional steep slope in the area just south of Royer Lake show a significant potential for field erosion (see Figure 19).

Table 78. Royer Lake characteristics

Characteristic	Value	Source
Lake total surface area (ac)	65	USGS National Hydrography Dataset
Lake volume (ac-ft)	1,560	Calculated (surface area x mean depth)
Mean depth (ft)	24	Calculated based on Indiana DNR August 1956 hydrographic survey prepared cooperatively by the USGS
Maximum depth (ft)	56	Indiana DNR August 1956 hydrographic survey prepared cooperatively by the USGS
Drainage area (acres)	3,608	USGS Indiana StreamStats application & EOR
Watershed area: lake area	56	Calculated (watershed area / lake area)
Upstream Lakes*	none	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported 'Drainage area' in this table.

Land Cover

At present, the dominant land cover in the Royer Lake watershed is cultivated crops (Table 79).

Table 79. Royer Lake Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage	
	Acres	% of Watershed
Barren Land	-	-
Cultivated Crops	1801	50%
Deciduous Forest	155	4.3%
Developed, Low Intensity	56	1.6%
Developed, Medium Intensity	2.6	0.071%
Developed, High Intensity	-	-
Developed, Open Space	138	3.8%
Emergent Herbaceous Wetlands	6.7	0.19%
Evergreen Forest	31	0.87%
Hay/Pasture	552	15%
Herbaceous	23	0.65%
Mixed Forest	-	-
Open Water	9.1	0.25%
Shrub/Scrub	-	-
Woody Wetlands	833	23%
Total*	**3608**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Water Quality

Phosphorus monitoring data are available from 1993, 2000, and 2003. The lake does not meet lake water quality standards for TP (Table 80). Table 30 shows additional detail regarding the phosphorus monitoring data available for Royer Lake.

Table 80. Royer Lake surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.040	0.030
Chlor-*a* (µg/L)	0.65	none
Secchi transparency (m)	2.0	none

Existing Phosphorus Loading

Watershed Phosphorus Loading

The contributing watershed to Royer Lake includes watershed runoff coming from the direct drainage to the lake. There are no upstream lakes in Royer Lake watershed. It is estimated that Royer Lake receives 4,448 pounds of phosphorus annually from external sources (Table 81).

Table 81. Royer Lake external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	4448	100%
Upstream Lake Loading (none)	-	-
Total*	**4448**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Internal Phosphorus Loading

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in Royer Lake is higher than the average of the field datasets used for development of the BATHTUB model.

Royer Lake monitoring data indicate that internal loading is a source of phosphorus to the lake. Dissolved oxygen concentrations were below 1 mg/l at a depth of 4 meters and below. At these low dissolved oxygen concentrations, phosphorus is released from the sediment to the hypolimnion and mixes with the surface water when the water column mixes during fall turnover. Royer Lake's monitoring data during thermal stratification is evidence of this process occurring; during three of the four days that were monitored, hypolimnetic (bottom water) soluble and total phosphorus concentrations were higher (at least double) than epilimnetic (surface water) concentrations (Table 82). This phosphorus is then available for algal uptake and growth during the following growing season.

Table 82. Royer Lake water quality data from Clean Lakes Program Data Summary

Date	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
	Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
1989	0.001	0.32	0.04	0.34
1993	0.003	0.25	0.05	0.30
7/10/2000	0.01	0.01	0.04	0.05
7/01/2003	0.01	0.17	0.01	0.18

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l

Clean Lakes Program data summaries indicate that blue-green algal dominance was high (96% in 2000 and 2003), indicating eutrophic conditions.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Royer Lake is 3536 lb/yr, to be split among allocations according to Table 83. To meet the TMDL, the total load to the lake needs to be reduced by 912 lb/yr, or 21%. There are no NPDES-permitted sources in the North Twin Lake watershed; therefore, there are no individual WLAs.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 83. Royer Lake allocation summary

Allocation*	lb/yr	lb/day
TMDL	3536	9.7
MOS	354	0.97
WLA	0.0	0.0
LA	3182	8.7

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Implementation Strategy

Royer Lake is in the East Fly Creek HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the Royer Lake watershed. The majority of the land use in the watershed is agricultural in nature, and there is one CFO in the watershed. The pollutant sources and management practices for the East Fly Creek HUC 12 watershed (**Error! Reference source not found.**) apply to the Royer Lake watershed, in addition to the other sources and implementation approaches identified in Table 84. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 84. Implementation approaches to addresses sources in Royer Lake watershed

Type	Source Summary	Implementation Section
Soil Erosion	Highly erodible soils with the occasional steep slope in the area just south of Royer Lake show a significant potential for field erosion (see Figure 19 on page 37)	**Error! Reference source not found.**
Internal Loading	Phosphorus release due to anoxic hypolimnion	B.1.1
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**

<u>Potential Priority Implementation Areas</u>

- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the CFO, land application of manure and other fertilizers, and droppings from working horses.
- Potential field erosion in the drainage area south of Royer Lake.

B.1.1 Lake Internal Loading

Once watershed runoff gets into a lake, some of the phosphorus is directly available for algae and plant uptake, while another portion, bound to soil particles present in the watershed runoff, settles to the lake bottom and can be recycled to a form that can be used for algal and plant growth at a later date. Decaying algae also falls out of the water column and is deposited on the lake bottom, where it becomes another source of phosphorus that can be recycled back into the water column.

Over time, a considerable amount of phosphorus can accumulate in the bottom sediment of a lake. This phosphorus can be recycled back to the water through a variety of processes. Insect larvae, bottom feeding fishes, wave action, and disturbance from boats can physically stir and resuspend phosphorus-bound sediment into the water. Resuspended phosphorus can chemically release from sediment particles and become available for algal and plant uptake. Plants can also recycle sediment phosphorus by taking it up through their roots and then releasing it into the water column as they decay.

Internal loading control techniques are those that are conducted in the lake itself and may include physical, chemical, and biological components. No single management practice or approach will resolve the problem of internal loading. The following is a description of internal loading control techniques generally recommended for the lakes in the Pigeon River Watershed. Further data collection will be needed for many of the lakes to determine the applicability of these practices to each lake.

Aquatic Plant Management

Shallow lakes depend on the aquatic macrophyte community to provide refuge for zooplankton and fish and maintain a healthy lake. Invasive aquatic plant species can increase phosphorus recycling within a lake and harm ecosystems. Once introduced, invasive species can spread to new areas and can rarely be eliminated.

Curly-leaf pondweed is an invasive aquatic macrophyte that disrupts the natural phosphorus cycle in the lake by dying off in the mid-summer, releasing phosphorus that is then available for algal growth. This plant also has a competitive advantage over other aquatic plant species because it starts to grow well before ice off, outcompeting the other plants for light. This invasive plant should be controlled immediately to prevent an infestation. Herbicide treatments are generally the most cost-effective method of control and are applied when water temperatures reach 50 to 55˚F.

In lakes with dense curly-leaf pondweed, there are often no other aquatic macrophytes present. In other cases, a lake does not have an established macrophyte community at all. There are many reasons for this, including use of herbicides, abundance of rough fish (which can cause uprooting of vegetation), lack of a viable seed bed, wind mixing, and sedimentation within the lake. The establishment of a healthy macrophyte community may require an evaluation of the seed bed to ensure adequate viability, and analysis of alternatives to establish macrophytes, including lake drawdown, fish management, and transplanting of vegetation. Establishing a healthy macrophyte community will require education of the shoreland owners and other stakeholders as well as costs associated with implementation.

In approximately 2006, the aquatic plant parrot feather (*Myriophyllum aquaticum*) was found in Meserve Lake. Parrot feather can be invasive, impairing recreational and ecological functions. Information on parrot feather and its control in Meserve Lake is included in the implementation strategy for Meserve Lake in Section 0.

Fish Management

The typical lake biological community consists of a broad base of primary producers (plants and algae) and consumers (animals). The primary producers support overlying levels of consumers, including herbivores (such as zooplankton), planktivores (which eat zooplankton), and much smaller numbers of piscivores (which eat other fish). Benthic organisms are consumers that live in, on, or near the lake bottom and forage in/near the sediments. Consumers often shift trophic levels throughout their life cycle.

Water quality can be affected if there is a disproportionate amount of any one of these biological communities.

Biomanipulation is the practice of undergoing lake improvement procedures that alter the food web to favor grazing on algae by zooplankton, or that eliminate fish species that disturb the bottom sediments. Biomanipulation can involve eliminating certain fish species or restructuring the fish community to favor a balance that allows sufficient survival of zooplankton.

Benthic fish management is one type of biomanipulation. An over abundance of benthivorous fish species such as carp and black bullhead can significantly degrade water quality by continually stirring up the lake sediment and re-suspending pollutants, especially phosphorus. One management strategy is to install fish barriers on a lake inlet and/or outlet, which prevents fish migration into areas of concern, coupled with a fish kill. Another management technique is to remove these species by conducting a water level drawdown, netting, or treating the lake with rotenone. Benthic fish removal typically occurs after fish barriers are constructed.

Zooplanktivore management is another type of biomanipulation. Overpopulation of zooplanktivores (such as crappie, sunfish, and bluegill) within a lake is a common problem because they can over-graze the zooplankton community, which causes increases in algal density. Reductions in densities of zooplanktivorous fish can be accomplished by adding predatory fish, conducting a water level drawdown, chemical (e.g. rotenone) treatment, and/or trapping.

Phosphorus Inactivation

Aluminum sulfate (alum) is a chemical addition that binds with phosphorus to form a non-toxic precipitate (floc). Alum reduces internal loading by binding with P and preventing its release, thereby forming a type of barrier between lake sediments and the water. In-lake alum treatments are often proposed to treat the deepest area of a lake and are not typically effective in shallow lakes or lakes that do not stratify. Alum treatments are only effective after external phosphorus inputs are significantly reduced, benthic fish have been removed, and fish barriers are installed to prevent their re-introduction.

Lake Drawdown

Drawdowns lower water levels in a lake in order to improve water quality and aquatic habitat. Lowering the water level in the winter exposes the sediment to both freezing and loss of water. A drawdown of lake levels can improve a lake's littoral vegetation through aeration of the sediments to allow the germination of certain native plant seeds; winter freeze-out of curly-leaf pondweed turions (dormant vegetative propagules); consolidation of the sediments to improve the sediment's ability to support rooted macrophytes; and promotion of oxygenation and consolidation of organic debris.

Summer drawdowns expose and consolidate the sediments, enhance conditions for the growth of perennial emergent species of aquatic vegetation, and consolidate the undesirable fish species for more efficient removal.